The Engineering Society For Advancing Mobility Land Sea Air and Space ®

A Product of the Cooperative Engineering Program

SAE J1113 AUG87

Electromagnetic Susceptibility Measurement Procedures for Vehicle Components (Except Aircraft)

SAE Recommended Practice
Revised August 1987

Submitted for Recognition as an American National Standard

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
400 COMMONWEALTH DRIVE, WARRENDALE, PA 15096

HIGHWAY VEHICLE PRACTICE

Submitted for recognition as an American National Standard

J1113

Issued April 1975
Revised Aug. 1987

Superseding J1113 JUN84

Ø ELECTROMAGNETIC SUSCEPTIBILITY MEASUREMENT PROCEDURES FOR VEHICLE COMPONENTS (EXCEPT AIRCRAFT)

1. INTRODUCTION:

1.1 Scope: This SAE Recommended Practice establishes uniform laboratory measurement techniques for the determination of the susceptibility to undesired electromagnetic sources of electrical, electronic, and electromechanical ground-vehicle components. It is intended as a guide toward standard practice, but may be subject to frequent change to keep pace with experience and technical advances, and this should be kept in mind when considering its use.

1.2 Measurement Philosophy: The need for measurement of the susceptibility of vehicle electronic components to electromagnetic sources has become more essential as more electronic components are introduced into motor vehicles. Electronic and electrical equipment may be susceptible to performance anomalies when subjected to electromagnetic sources, either of a transient or steady-state nature.

Electromagnetic interference (EMI) may be transient, intermittent, or continuous in nature arising from sources such as transmitters or other equipment located either on board or adjacent to the vehicle, or from component parts of the vehicle ignition or electrical power systems.

This recommended practice sets forth uniform procedures for establishing the susceptibility levels of individual vehicle components. It does not set limits on levels of EM energy in which vehicle components must perform; however, suggestions for developing functional performance status classifications for immunity are given in Appendix B.

1.2 (Continued):

A direct method of specifying the EM energy environment limits is to measure the actual fields, voltages, current, and impedances around the component or system of interest under all hazardous conditions. This will, of course, require a large enough sample of installations to determine possible variations. Some example data showing fields exists in NBS Technical Note 1014, "Electromagnetic Interference (EMI) Radiative Measurements for Automotive Applications."

It is recommended that a statistically valid number of components be tested using procedures adopted as standard by the testing organization. For destructive testing, such as transients on the power leads of Section 4, consult a handbook on statistical methods for details of the Karber method or the Bruceton (stair-step) method of sensitivity measurements. These methods eliminate the effects of cumulative degradation which often occurs during destructive testing.

It is suggested that only those portions of this recommended practice which are critical to the particular use of the component under test be applied, rather than subject the component to the provisions of the entire document. Thus, if the particular component under test is known to be susceptible mainly to transients, but otherwise well protected against conducted and radiated EMI, then only Section 4 need be applied. Or, if susceptibility to radiated energy is known to be a primary cause of malfunctions, then only Sections 6 through 9 need be applied.

Caution must be exercised in many portions of this procedure where high voltages or intense fields may be present.

ANSI and OSHA standards should be consulted concerning applicable limits on field exposure. For near field power density calculations, refer to paragraph 1.3.7.

1.3 <u>Definitions and Terminology</u>: The following definitions apply to the terms indicated as they are used in this recommended practice:

1.3.1 <u>Ambient Level</u>: Those levels of radiated and conducted signal and noise existing at a specified test location and time when the test sample is in operation. Atmospherics, interference from other sources, and circuit noise or other interference generated within the measuring set compose the ambient level.

1.3.2 <u>Conducted Emission</u>: Desired or undesired electromagnetic energy which is propagated along a conductor.

1.3.3 <u>Electromagnetic Compatibility (EMC)</u>: Is the condition that enables equipment, subsystems, and systems (electronic, chemical, biological, etc.) to function without degradation from electromagnetic sources and without degrading the electromagnetic environment; that is, it is the condition which allows the coexistence of different electromagnetic sources without significant change in performance of any one in the presence of any or all of the other.

1.3.4 Emission: Electromagnetic energy propagated from a source by radiation or conduction.

1.3.5 Equipment Under Test (EUT): The device or system whose susceptibility is being checked.

1.3.6 Field Decay (Voltage): The exponentially decaying negative voltage transient such as developed by an automotive alternator when the field excitation is suddenly removed, as when the ignition switch is turned off.

1.3.7 Field Strength: The term field strength shall be applied to either the electric or the magnetic component of the field, and may be expressed as V/m or A/m. When measurements are made in the far field and in free space, the power density in W/m^2 may be obtained from field strengths approximately as $(V/m)^2/377$ or $(A/m)^2 \times 377$. When measurements are made in the near field and in free space, both the complex electric and magnetic vector components of the field must be fully defined. Power density may then be obtained by use of the Poynting vector.

1.3.8 Ground Plane: A metal sheet or plate used as a common unipotential reference point for circuit returns and electrical or signal potential.

1.3.9 Load Dump (Voltage): The exponentially decaying positive voltage transient developed by an automotive alternator when disconnected, suddenly from its load, while operating without a storage battery or with a discharged storage battery. Removal of the load, the resulting transient, or both in combination are commonly referred to as alternator load dump.

1.3.10 Radiated Emission: Radiation - and induction-field components in space. (For the purpose of this document, induction fields are classed together with radiation fields.)

1.3.11 Spurious Emission: Any unintentional electromagnetic emission from a device.

1.3.12 Susceptibility: The characteristic of an object that results in undesirable responses when subjected to electromagnetic energy.

1.3.13 Test Plan: The specific document that details all tests and limits for the particular device in question.

2. CONDUCTED SUSCEPTIBILITY, 30 HZ TO 250 KHZ - ALL INPUT AND OUTPUT LEADS INCLUDING POWER:

2.1 Purpose: This section covers the requirements for determining the susceptibility characteristics of automotive electronic equipment, sub-systems, and systems to EM energy injected onto all leads. This test may be used over the frequency range of 30 Hz to 250 kHz.

2.2 Measurement Philosophy: For the frequency range of this test, the impedances seen by the signal, load and power supply leads are generally known and can be treated as lumped constants. In this test, a wide range audio voltage source is coupled through a transformer to each specified pin of the EUT. The signal source impedance must be low in comparison to the impedance of the circuit being tested. Experience has shown that a signal source impedance of 0.5 ohms maximum is adequate for the test. The EUT should be connected so it will operate in its normal manner. Actual loads and sources should be used where appropriate or may be simulated. A capacitor shunt element should be used on a specific lead, if a large percentage of the test signal does not appear across the signal, load or power supply lead relative to ground. (See Fig. 1.)

2.3 Grounding and Shielding: For the stated frequency range there are no special grounding and shielding requirements. However, the requirements of paragraph 3.3 may be utilized here, if expedient.

2.4 Apparatus: To utilize the full frequency range of this test, the apparatus shall be as follows:

(a) Audio Oscillator: 30 Hz to 250 kHz.

(b) Audio Power Amplifier: 50 W or greater with output impedance equal to, or less than, 2.0 Ω (capable of delivering 50 W into a 0.5 Ω resistive load connected across an isolation transformer secondary). 30 Hz to 250 kHz

(c) Isolation transformer: 4:1 impedance ratio; secondary as connected shall be capable of handling the current flow without saturating the core. 30 Hz to 250 kHz

(d) Measuring Instrument: Oscilloscope, Voltmeter, or EMI Meter.

(e) Power Supply: The power supply used for this test shall have the equivalent of 100 μf (min) capacitor across the output terminals.

(f) Capacitor: A 100 μf capacitor may be used to shunt the source end of the isolation transformer to ground, if difficulty is encountered in obtaining sufficient test voltage.

2.5 Test Setup and Procedures: The test setup is shown in Fig. 1.

(a) The system power supply voltage shall be set as specified in the test plan.

(b) The audio oscillator shall be tuned through the required frequency range (30 Hz to 250 kHz).

(c) The injected voltage level shall be progressively increased toward the level specified in the test plan. Alternatively, the test voltage may be held at a specified test level and, if an effect on the EUT is detected, the test voltage reduced to determine the threshold.

2.5 (Continued):

(d) The EUT shall be monitored for (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the equipment specification or the test plan.

(e) The effects resulting from the injection of electromagnetic energy, the frequency and the threshold level shall be recorded.

2.6 Notes:

2.6.1 The upper frequency limit for items 2.4a, 2.4b, and 2.4c can be reduced in accordance with the user's frequency range requirements.

2.6.2 It is recognized that other types of equipment can produce equivalent signals, for example, a Power Oscillator can replace the oscillator and amplifier; a Power Operational Amplifier can replace the amplifier and power supply, etc.

2.6.3 The following procedure can be used to verify the signal source impedance at the isolation transformer secondary terminals.

(a) Set a voltage level at the primary terminals and measure the open circuit secondary voltage (V_{OC}).

(b) Connect a known load R_L across the secondary and measure the closed-circuit secondary voltage (V_{CC})

(c) The impedance shall be calculated as follows:

$$Z = \frac{R_L\ (V_{OC} - V_{CC})}{V_{CC}} \quad (\Omega)$$

(d) Repeat the above procedure at one frequency per decade from 30 Hz to 250 kHz (including 30 Hz and 250 kHz).

(e) The measured impedance shall be less than, or equal to 0.5Ω.

3. CONDUCTED SUSCEPTIBILITY, 50 KHZ TO 100 MHZ - ALL INPUT AND OUTPUT LEADS, INCLUDING POWER:

3.1 Purpose: This section covers the requirements for determining the susceptibility characteristics from 50 kHz to 100 MHz of automotive electronic equipment, subsystems, and systems to EMI injected onto all input leads, including signal and power.

3.2 Measurement Philosophy: Power-source RF impedance seen by a given type of electronic equipment depends upon this varying impedance and would render susceptibility measurements meaningless unless the impedance is also measured or controlled. In order to compare measurements made at various locations, powerline RF impedance seen by the equipment shall be controlled by line-impedance stabilization networks. The EUT should be connected so it will operate in its normal manner. Actual loads and sources should be used where appropriate or may be simulated.

3.3 Grounding and Shielding: To achieve uniform measurement conditions at radio frequencies requires that certain grounding practices be followed. Ground requirements are that EUT, LISNs, and terminating loads:

(a) be placed on a metallic ground plane having the following minimum dimensions:

1. Thickness: 1.5 mm (0.060 in) aluminum, copper, or brass sheet.
2. Length: 1 m or underneath entire equipment plus 0.5 m whichever is larger.
3. Width: width of equipment plus 0.25 m on each side.

(b) be bonded to the ground plane as in its intended installation.

(c) not otherwise be grounded, unless required in installation instructions. The line-impedance stabilization networks shall be bonded to the ground plane as close as possible to the EUT ground. No shielding is to be used other than that called out in installation instructions.

3.4 Power Input Lead Test:

3.4.1 Apparatus:

(a) Signal Source: A 50 Ω output-impedance source with an output of 100 V or greater into a matched load.

(b) One of the following to measure RF voltage:

1. Calibrated Oscilloscope
2. High Impedance RF Voltmeter
3. EMI Meter
4. Spectrum Analyzer

(c) Line-Impedance Stabilization Networks (LISN's): as specified in Figs. 2 and 3 with 50 Ω resistive RF terminations. (See Appendix A for suggestion of construction details.) When using a LISN, caution should be exercised to avoid load-current limiting due to series inductance in the LISN. This limiting may occur when loads switch between high and low impedance states. Use of a LISN may then result in increased susceptibility.

(d) Test-Source Injection Networks illustrated in Fig. 4.

(e) Power Supply: DC.

3.4.2 Test Setup and Procedure: The test setup is shown in Fig. 5. The procedure is as follows:

(a) Each control and signal lead shall be loaded with a termination impedance. At these frequencies, however, the impedance as seen by the control and signal leads may no longer be determined by the system designer, due to uncontrollable stray impedances. It may be possible to simulate these impedances with a simple capacitor and inductor added to the actual leads if the frequency in MHz does not greatly exceed $300/20\pi\ell$ where the ℓ is the characteristic lead length in meters. Above that frequency, the test designer should design the test plan and setup to given uniform results.

(b) The EUT shall be connected as shown in Fig. 5, observing the grounding and shielding requirements of paragraph 3.3.

(c) Signal sources and measuring instrumentation shall be connected to an LISN through test-source injection networks. Care shall be exercised to insure sufficiently short leads on the injection networks and LISN's to minimize loss of signal due to series inductance and shunt capacitance. A current probe on the injection lead right next to the EUT can be used to monitor the signal. For signal-source and measuring-instrument impedance equal to 50 Ω, use the signal-injection network of Fig. 4A. For a signal-source impedence of 50 Ω and a high-impedance measuring instrument, use the signal-injection network of Fig. 4B. Note the corresponding attenuation factors.

(d) Increase the level of the test signal while continuously scanning through the required frequency range (50 kHz - 100 MHz). Tests shall be conducted at not less than three frequencies per octave representing the maximum susceptibilities within that octave. Monitor the equipment under test for: (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the equipment specification or approved test plan (see paragraph 3.6). Record the highest level before degradation was observed.

(e) See paragraph 2.5(c).

3.5 All Leads Except Power:

3.5.1 Apparatus:

(a) Signal Sources: as for powerline measurements.

(b) Measuring Instruments: as for powerline measurements.

(c) Test Source Injection Networks: see Fig. 4.

3.5.2 Test Setup and Procedure:

(a) Test setup is shown in Fig. 6. Note that the LISN remains in the powerline circuit and its RF injection terminal is loaded with 50 Ω.

(b) Each control and signal termimal not under test is loaded with its terminating impedance and test signals are injected into the test terminal as indicated in Fig. 6. At these frequencies, however, the impedances seen by control and signal leads may no longer be determined by the system designer. It may be possible to simulate the stray impedance as described in paragraph 3.4.2(a). Care shall be exercised to insure sufficiently short leads on the injection networks and LISN's to minimize loss of signal due to series inductance and shunt capacity. A current probe on the injection lead right next to the EUT can be used to monitor the signal.

(c) Increase the level while continuously scanning through the required frequency range (50 kHz - 100 MHz). Tests shall be conducted at not less than three frequencies per octave representing the maximum susceptibilities within that octave. Monitor the EUT for: (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the equipment specification or approved test plan. (See paragraph 3.6.) The values at which these occur shall be recorded.

3.6 Notes:

(a) Each LISN shall be tested over the range for which it is designed. The impedance should be within 20% of the curves in Figs. 2 and 3. If any discrepancies occur, then the network should be modified, for example, by adding ferrites to inductor leads to increase impedance at higher frequencies.

(b) Unless otherwise required in the equipment specifications or approved test plan, the test signals shall be modulated according to the following rules:

1. Test samples with audio channels/receivers.
   AM Receivers: Modulate 30% with 1000 Hz tone.
   FM Receivers: Modulate with 1000 Hz signal using 30% modulation.
   SSB Receivers: Use no modulation.
   Other Equipments: Same as for AM receivers.
2. Test samples with video channels other than receivers. Modulate 90 - 100% with pulse of duration 2/BW and repetition rate equal to BW/1000, where BW is the video bandwidth (Hz).
3. Digital Equipment: Use pulse modulation as appropriate with pulse duration and repetition rate set equal to that used in the equipment under test or associated with other known external pulse sources that may be operating in close proximity.
4. Non-Tuned Equipment: Amplitude modulate 30% with 1000 Hz tone or as otherwise specified in the test plan.

4. CONDUCTED SUSCEPTIBILITY, TRANSIENTS, POWER LEADS 12 V PASSENGER CAR SYSTEMS:

4.1 Purpose: This section describes methods and apparatus to determine the capability of various electrical devices to withstand transients which normally occur in motor vehicles. Test apparatus specifications outlined in this section were developed for 12 V passenger cars. Similar specifications are being developed for 12 V trucks and 24 V vehicles.

Functional performance status classifications for immunity to transients are given in Appendix B. EUT performance requirements for each of the test pulses must be individually determined.

4.2 Measurement Philosophy: Installed equipment is powered from sources which contain, in addition to the desired electrical voltage, transients with peak values many times this value, caused by the release of stored energy during the operation of relay and other loads connected to the source and during start and turn off of vehicles. These tests are designed to determine the capability of equipment to withstand such transients. The tests may be made in the laboratory (bench tests) as well as on the vehicle. These tests are outlined in ISO/TR 7637, "Road Vehicles - Electrical Interference by Conduction and Coupling: Part 1, Vehicles with Nominal 12 V Supply Voltage - Electrical Transient Conduction Along Supply Lines Only." Bench test methods should give results which allow comparison between different laboratories and are intended to provide a basis for development of devices and systems. These tests may also be used later during production of these devices and systems.

These tests may not cover all types of transients which can occur in a vehicle. Therefore, the test pulses described in paragraph 4.3 are characteristic of typical pulses. To ensure proper operation of a vehicle in the electromagnetic environment, on-board testing must be performed in addition to bench testing.

4.3 Apparatus:

(a) Pulse generators capable of generating the transient waveforms shown in Figs. 7A - 7H shall be adjustable up to the amplitudes indicated. The specification of rise time (T_r), duration (T), and internal resistance (R_i) represent fixed requirements unless otherwise specified.

(b) Oscilloscope (preferably storage): for monitoring the pulse generator
band width: at least 100 MHz
writing speed: at least 100 cm/μs
input sensitivity: at least 5 mV/division

4.3 (Continued):

(c) Voltage Probe: for use in conjunction with the oscilloscope.
attenuation - 100/1
maximum input voltage - at least 1 kV
input impedance as a function of the frequency, f:

f (MHz)	Z (kΩ)
1	40
10	4
100	0.40

maximum length of the probe cable - 3 m
maximum length of the ground cable - 0.13 m

Note: Any other cable lengths may influence the result of the measurement and should be stated in the test report.

(d) Switch S: Use standard production switch for the respective EUT. Current rating must be sufficient to handle the required loads.

(e) Equipment, as may be required, to perform a functional test of the component following transient application.

4.4 Test Setup and Procedure:

(a) Connect a known functional EUT as shown in Fig. 8.

(b) Ensure that the ambient temperature and supply voltage V_S are maintained as required by the appropriate test specification.

(c) Set up the pulse generator to provide the polarity, amplitude, and pulse duration as specified in the appropriate test specification.

(d) Generate the test pulse.

(e) Perform the appropriate functional test to determine whether failure has occurred and record results.

4.5 Notes:

(a) In determining the susceptibility level, care must be exercised to eliminate the effects of cumulative deterioration such as dielectric "punch through" in semi-conductor devices.

(b) When testing to a specified level, unnoticed failures may occur which may be detected only by running life-cycle tests and comparing the results of tested components against those of untested components.

(c) Rise time requirements as specified in Figs. 7A - 7H represent a design objective. For short duration, high voltage pulse, some rise times may not be practical.

4.5 (Continued):

(d) The ambient temperature during the test shall be 23 ± 5 °C.

(e) Power leads should be separated from all other leads for these tests.

5. ELECTROSTATIC DISCHARGE:

5.1 Purpose: This section covers the requirements for determining the susceptibility of automotive electronic components/subsystems to Electrostatic Discharge (ESD).

5.2 Measurement Philosophy: Occupants in a vehicle can generate significant electrostatic potentials. Devices in the vehicle may fail when an electrostatic discharge occurs.

Electrostatic discharge simulator parameters for use in automotive applications are unique to the automotive environment and differ from values used in other applications.

5.3 Apparatus:

(a) ESD Simulator characteristics:
- Voltage Range: variable from 1 kV to 15 kV (negative and positive polarity)
- Capacitor: 330 pF (± 10%)
- Inductor: < 1 μH
- Resistance: 2000 Ω (± 10%)
- Tip: standard (IEC) finger model electrode. (See IEC 801-2)

ESD simulators are commercially available. Appendix C defines a test method for evaluating the characteristics of the simulator to ensure the generation of accurate and reproducible discharge waveforms.

(b) Conductive Bench Top, at least 1 m^2.

5.4 Test Procedure:

(a) The device shall be placed on a conductive-bench top as shown in Figs. 9A and 9B. All voltage supply pins should be connected to an appropriate power source. All ground pins should be connected together. The ground pins, bench top, ESD simulator, and power source shall be grounded together and to earth ground. All other pins shall be connected to simulate normal modes of operation.

(b) The method of air discharge to a point shall be used to simulate a real world ESD event. The ESD simulator must be charged to the "test voltage" before approaching the EUT. Approach the EUT at a speed approximating a "normal" interface by a human finger (greater than 5 cm/s).

5.4 (Continued):

(c) Twenty discharges shall be applied to specified test points at each voltage level; ten with positive polarity and ten with negative polarity. A minimum of five (5) s shall be maintained between pulse applications.

If significant variations are observed in the measurement data, twenty discharges may not be sufficient to obtain statistically significant results. If this is found to be the case, a larger number of discharges will be required.

(d) During and after each level of testing, the device shall be measured for performance which may indicate failure to meet design requirements.

6. RADIATED SUSCEPTIBILITY, POWER LINE MAGNETIC FIELD 60 HZ TO 30 KHZ:

6.1 Purpose: This section covers the recommended testing technique for determining the susceptibility of automotive electronic modules, subsystems, and systems to magnetic fields generated by power transmission lines and generating stations.

6.2 Measurement Philosophy: Electronic systems may be affected when immersed in a magnetic field. These fields are found near high power transmission lines and power generating stations that generate magnetic fields. The fields consist of the fundamental (60 Hz signal) and its odd harmonics with amplitudes approaching those shown in Fig. 10. Consequently, devices in vehicles that are driven near these sources may be subjected to these fields.

6.3 Test Specification:

(a) Lower frequency: 60 Hz.
(b) Upper frequency: 30 kHz.
(c) Magnetic flux density of Helmholtz coil - see Fig. 10.

6.4 Test Apparatus: The following section describes a typical test setup that could be used to generate a uniform magnetic field for the testing as illustrated in Fig. 11.

(a) Helmholtz Coil: The radius of the coil will be determined by the size of the EUT. In order to obtain a uniform magnetic field ($\pm$ 10%), the relationship between the EUT and the coil is illustrated in Fig. 12. The coil should be capable of producing frequency dependent magnetic flux density of 160 dBpT at 60 Hz, decreasing at a rate of 12 dB/octave. For a pair of Helmholtz coils spaced one radius, the magnetic flux density at the center of the system is given by:

$$B = \mu_o H = (8.991 \times 10^{-7} N I)/R \text{ (Teslas)},$$

where N is the number of turns on each coil, R is the coil radius in meters, and I is the coil current in amperes. The coils are connected in series so that the magnetic fields add.

6.4 (Continued):

Or, the unperturbed magnetic field at the center of the system is given by:

$$H = \frac{0.7155\ N\ I}{R} \quad (A/m),$$

The current carrying capability and turn ratio should be selected such that the test specification can be met. The coil should not have a self resonant frequency at or lower than the upper test frequency. Helmholz coils can be purchased commercially.

(b) Function generator capable of producing 60 Hz to 30 kHz.

(c) Audio Power Amplifier: 60 Hz to 30 kHz (approximately 200 W). Should be capable of delivering power to the coil to generate the specified magnetic field intensity at various frequencies as shown in Fig. 10.

(d) Current Monitor: 60 Hz to 30 kHz.

(e) Magnetic Field Intensity Monitor: 60 Hz to 30 kHz. Should be capable of measuring the specified magnetic field intensity.

6.5 Test Setup and Procedure:

(a) Connect the test setup according to Fig. 11 without the EUT.

(b) Calibrate the system by generating the magnetic field, measuring the field using the intensity monitor and recording the current versus field values.

(c) Place the operating EUT in the central region of the Helmholtz coil. (Note: The Helmholtz coil criteria should be met.) Generate the desired magnetic field levels in accordance with the calibration established in paragraph 6.5 (b).

(d) Monitor the EUT and record the respective magnetic field intensity for: (1) malfunction, (2) degradation of performance, or (3) deviation of parameters beyond tolerances indicated in the EUT specifications and approved test plan.

6.6 Notes: Caution must be exercised when operating high power amplifiers to avoid hazards to personnel and instrumentation. Instrumentation in the near vicinity of the coils must be shielded to prevent interference from radiated fields. Care should be exercised not to operate the coils near large metal objects or inside a shielded enclosure.

7. RADIATED SUSCEPTIBILITY, 14 KHZ - 200 MHZ, ELECTRIC AND MAGNETIC FIELDS USING A TEM CELL:

7.1 Purpose: This section covers requirements for the determination, typically, of the electric-field susceptibility of equipment, subsystems, and systems (whose largest dimension is less than 15 cm) in the frequency range 14 kHz - 200 MHz using a TEM cell. However, since components of both the electric and magnetic fields are established in the TEM cell, the technique can be used for both electric and magnetic field susceptibility testing.

7.2 Measurement Philosophy: A TEM transmission cell is a rectangular adaptation of a coaxial line which sets up a region of uniform electric and magnetic fields in a traveling wave of essentially free-space impedance. The EUT is exposed to this electromagnetic source, but, typically, only the electric-field component is monitored. However, since components of both the electric and magnetic field are present, the exposure field can be calibrated in terms of either electric or magnetic field for either electric or magnetic field susceptibility testing.

This technique also prevents disturbance to equipment not under test since the RF field source and EUT are completely self-contained within the electromagnetic enclosure.

The TEM cell can be used to accurately generate absolute test fields when the EUT does not occupy an excessive portion of the test volume (see paragraph 7.5 c). It is especially useful for diagnostic testing to determine, for example; frequencies of EUT susceptibility, some indication of how interference is coupled into the EUT, and the relative improvement in EUT immunity resulting from efforts to reduce EUT susceptibility. It cannot be used to determine EUT susceptibility to absolute test field levels if the EUT includes long wire harnesses that must be exposed to the test field. Only relative tests can be performed for this situation. The TEM cell lends itself to broadband automated testing and to continuous, swept frequency testing over the complete frequency range covered by the single TEM mode operation of the cell. TEM cell limitations due to EUT size and cell multimoding are discussed in SAE J1448 JAN84 (see Ref. 8). An alternate measurement approach is the use of open field tests as outlined in the SAE J1338 JUN81 (see Ref. 9). This approach however, is limited to discrete frequencies.

7.3 Apparatus:

(a) Signal Source: Any commercially available signal source, power amplifier, and general-purpose amplifier capable of supplying at least 100 W of modulated and unmodulated power to develop the susceptibility levels specified in the test plan shall be used. Frequency accuracy shall be within ± 2%. Harmonics and spurious outputs shall not be more than - 30 dB referred to the fundamental power.

(b) RF Voltmeter: A commercially available RF voltmeter capable of measuring 100 V over the frequency range 14 kHz - 200 MHz.

7.3 (Continued):

(c) Termination: One 200 W, 50 Ω load.

(d) Frequency Counter: A frequency counter capable of measuring frequencies up to 200 MHz.

(e) TEM Transmission Cell: a transverse electromagnetic transmission cell is shown in Fig. 13.

(f) Low-Pass Filter: Cutoff at 200 MHz, with the signal down 60 dB at frequencies greater than 300 MHz.

(g) Monitors: Required test equipment to monitor the operation of the EUT.

(h) Dual Directional Couplers: -30 dB or greater coupling ratio, 10 - 200 MHz.

(i) RF Power Meters With Sensors: Capable of Measuring RF power levels up to 100 mW at frequencies of 10 - 200 MHz.

(j) Dual Channel XY Recorder

7.4 <u>Test Setup and Procedure</u>: A detailed, step-by-step measurement procedure, suggested as a systematic approach for evaluating the EM radiated susceptibility of EUT is contained in SAE J1448 JAN84. Briefly, this includes:

(a) Place the EUT inside the cell as shown, for example, in Fig. 13.

(b) Access the EUT as required for operation and performance monitoring using appropriate shielded and fiber optic lines routed to filtered feed-through connectors mounted on the bottom outer shield as shown in Fig. 13. Care must be taken in routing the leads to obtain the most meaningful, repeatable results. Record lead positions for future reference.

(c) Connect up the measurement system as shown in Fig. 14a or 14b. Fig. 14A is used for frequencies below 10 MHz and Fig. 14B is used for frequencies above 10 MHz.

(d) Generate the test field as required. The field strength, E_o, at the center of the cell, midway between the septum and lower or upper wall is determined by:

$$E_o = \frac{V_{rf}}{b} \quad (V/m)$$

7.4 (Continued):

where V_{rf} is the input voltage to the cell in volts and b is the cell floor-to-septum separation in meters. At frequencies above 10 MHz, V_{rf} is determined from he expression:

$$V_{rf} = \sqrt{P_n/G_c} \quad (V)$$

where P_n is the net power flowing through the cell as measured by the power meters on the sidearm of the calibrated bi-directional coupler, and G_c is the real part of the cell's characteristics admittance (approximately = 0.2 mhos).

If the EUT is placed near the floor of the cell, the test field will be lower, relative to the field midway between the septum and floor. The correction is from 5 to 15% depending upon the cell form factor (width to height ratio, a/b) (that is, If a/b is 1.0, this correction factor is 0.85; if a/b is 1.5, this correction factor is 0.92; and if a/b is 1.67, the correction factor is 0.95).

(e) Operate the EUT as required while monitoring its response to the RF test fields. Scan the entire frequency range from 14 kHz to 200 MHz with particular emphasis made at the EUT's critical frequencies (local oscillator frequencies, intermediate frequencies, etc.) as specified in the test plan. Orient the EUT in each orthogonal plane within the cell to determine maximum susceptibility. Record the threshold of susceptibility as performance is observed or the maximum level specified in the test plan is achieved.

7.5 Notes:

(a) Unless otherwise required in the equipment specification or approved test plan, the test signals shall be modulated according to the following rules:

1. EUTs with audio channels/receivers
   AM Receivers: Modulate 30% with 1000 Hz tone.
   FM Receivers: When monitoring signal-to-noise ratio, modulate with 1000 Hz signal using 30% modulation. When monitoring receiver quieting, use no modulation.
   Other Equipment: Same as for AM receivers.
2. EUTs with video channels other than receivers - Modulate 90 - 100% with pulse duration of 2/BW and repetition rate equal to BW/1000, where BW is the video bandwidth.
3. Digital Equipment: Use pulse modulation with pulse duration(s) and repetition(s) equal to those used in the EUT.
4. Non-Tuned Equipment: Amplitude-modulate 30% with 1000 Hz tone, or as otherwise required in the test plan.

7.5 (Continued):

(b) Detailed considerations concerning EUT size, frequency limitations, and construction specifications can be found in SAE J1448 JAN84. In general, the device should be less than 1/3 the length (L), width (2a), and separation distance between cell septum and floor (b). Test samples of any size could be tested using a TEM cell modeled from Table 1 as long as the EUT size verses TEM cell size criteria defined above are satisfied. (These dimensions constraints prevent excessive impedance loading and test-field perturbation when inserting the EUT into the cell.) Thus, a small EUT could be tested at higher frequencies in small cells, and a large EUT could be tested at lower frequencies in a larger cell. The procedure for testing is the same for all sizes of cells except higher power signal sources and appropriate high-power terminations (50 Ω) are required when using larger cells to obtain the same test field levels.

(c) The upper useful frequency for a cell is limited by the distortion of the test signal caused by multimodes and resonances that occur within the cell at frequencies given in Table 1 (see Refs. 10, 11).

(d) The useful upper frequency for the cell is reduced 10-20% from the cutoff-multimode resonant frequency given in Table 1 to account for the loading effect of the EUT.

(e) Because the cell operates with the fundamental TEM mode, broadband CW testing with amplitude or frequency modulation is possible. In addition, the cell can be used to establish impulsive wave forms for testing by using an appropriate wave-form generator connected to the cell's input port, assuming the frequency content of the wave form does not exceed the multimode cutoff frequency of the cell.

Not all the tests oulined in this measurement procedure may be required, and only those required by the test plan should be performed. For example, if the objective of the measurement program is to reduce the vulnerability (susceptibility) of the EUT, one EUT orientation with one input/output lead configuration could be tested in one particular operational mode to a preselected susceptibility test-field waveform and amplitude. Then, if corrective measures were made to the EUT and placement of the EUT and its leads inside the cell were carefully duplicated, repeat measurements could be made. These measurements could then be compared to determine the degree of improvement.

8. RADIATED SUSCEPTIBILITY 14 KHZ - 1 GHZ, ELECTRIC FIELD AND MAGNETIC FIELD USING A STRIP LINE:

8.1 Purpose: This section covers requirements for the determination, typically, of the electric field susceptibility of equipment, subsystems, and systems (whose maximum height is less than 10 cm and maximum length is less than 2 m) in the frequency range 14 kHz to 1 GHz. However, since components of both the electric and magnetic fields are established in the line, the technique can be used for either electric or magnetic field susceptibility testing.

8.2 Measurement Philosophy: A strip line is a shieldless, unbalanced version of a TEM transmission line which sets up a region of uniform electric and magnetic fields in a traveling wave of essentially free-space impedance. The primary usage of the strip line is to couple RF onto the wire harness feeding the EUT. If desired, the EUT may also be tested using the strip line similar to using a TEM cell, Section 7, but with a proportionally smaller EUT. However, if the EUT is placed under the stripline, care must be exercised not to use the test setup above the multimode frequency of the stripline.

This technique is intended primarily for use in diagnostic testing to determine, for example, frequencies of EUT susceptibility, some indication of how interference is coupled into the EUT, and the relative improvement in EUT immunity resulting from efforts to reduce EUT susceptibility. It cannot be used to determine EUT susceptibility to absolute test field levels if the EUT includes long wire harnesses that must be exposed to the test field. This is because the wire harness is oriented longitudinally along the length of the strip line. Both the E and H fields are cross polarized with the wire harness for this configuration; hence, the coupling occurs mainly at the ends of the harness where it drops vertically to the EUT (aligned with the TEM E-field). It is also possible to induce RF onto the harness from differential mode coupling since the different wires are at different heights above the strip line's ground plate.

8.3 Apparatus:

(a) Signal Source: Any commercially available signal source, power amplifier, and general-purpose amplifier capable of supplying at least 100 W of modulated and unmodulated power to develop the susceptibility levels specified in the test plan shall be used. Frequency accuracy shall be within ± 2%. Harmonics and spurious outputs shall not be more than - 30 dB referred to the fundamental power.

(b) In-Line Wattmeter: A commercially available wattmeter capable of measuring 200 W over the frequency range 2 MHz to 1 GHz.

(c) RF Voltmeter: A commercially available RF voltmeter capable of measuring 100 V over the frequency range 14 kHz to 10 MHz.

(d) Frequency Counter: A frequency counter capable of measuring frequencies up to 1 GHz.

(e) Strip Line: A strip line is shown in Figs. 15A and 15B. The L dimension should be at least 2 m. The ratio of W to H determines the characteristic impedance according to the following equation:

$$Z_0 = \frac{120\,\pi}{W/H + 2.42 - 0.44\,H/W + (1 - H/W)^6} \quad \text{for } W/H > 1$$

Typical strip line is generally constructed to be either 50 or 96 Ω with W/H equal to 5 and 1.75 respectively. The resistive load can be constructed of carbon resistors, conductive strips, etc. such that it matches the characteristic impedance of the strip line minimizing the standing waves.

8.4 Test Setup and Procedure:

(a) Test setup should be as shown in Fig. 16.

(b) The EUT wire harness should be placed in a non-conductive fixture and placed in the center of the line supported 5 cm off the ground plane.

(c) The EUT must not be grounded to the strip line, but may be placed on a non-conductive pad located on the strip line ground plane.

(d) Generate the test field as required. For frequencies below $\lambda \geqslant 10L$, the field strength, E_V, can be measured by using an RF voltmeter where:

$$E_V = \frac{V_{rf}}{H} \text{ volts/meter}$$

For higher frequencies, a commercially available small field probe should be used to establish a calibration curve.

E_V can be monitored after establishing the calibration curve by:

$$E_V = \frac{\sqrt{PZ}}{H} \text{ volts/meter}$$

where P is the measurement forward power into the strip line in watts, Z is the strip line impedance in ohms, and H is the strip line spacing in meters.

(e) The EUT shall be operated by its normal inputs, where possible, and by simulators external to the strip line, filtered as required.

8.5 Notes:

(a) Unless otherwise required in the equipment specification or approved plan, the test signals shall be modulated according to the following rules:

1. Test samples with audio channels/receivers
AM Receivers: Modulate 30% with 1000 Hz tone.
FM Receivers: When monitoring signal-to-noise ratio, modulate with 1000 Hz signal using 30% modulation. When monitoring receiver quieting, use no modulation.
Other Equipment: Same as for AM receivers.
2. EUT's with video channels other than receivers. Modulate 90 - 100% with a pulse of duration 2/BW and repetition rate equal to BW/1000 where BW is the video bandwidth.
3. Digital Equipment: Use pulse modulation with pulse duration(s) and repetition rate(s) equal to those used in the equipment.
4. Non-Tuned Equipment: Amplitude modulate 30% with 1000 Hz tone or as otherwise required in the test plan.

(b) At frequencies over $\lambda = 2L$, and 2W, moding may occur which will reduce the accuracey of the fields generated by the strip line.

8.5 (Continued):

(c) At frequencies over λ = 4H, the strip line will radiate energy.

(d) If the EUT occupies a significant portion of the volume between the plates, the test field will be perturbed, resulting in a stronger field than that indicated by the measured forward power.

(e) Since the RF field is not self-contained, the test must be performed in a shielded room with the generating and monitoring equipment being outside the room. Energy radiated from the line into the enclosure will result in room resonance which can cause large errors. This effect can be reduced significantly by installing RF absorbing panels. These panels reduce the level of the reflections from the walls of the shielded room.

9. RADIATED SUSCEPTIBILITY, 200 MHZ - 18 GHZ, PLANAR FIELD (FAR-FIELD):

9.1 Purpose: This section covers the requirements for the determination of electric-field susceptibility of equipment, subsystems, and systems in the frequency range 200 MHz - 18 GHz.

9.2 Measurement Philosophy: At frequencies about 200 MHz, TEM cells become too small to test many types of equipment. However, RF absorbing material becomes effective and measurements can be made within an RF shielded enclosure provided RF absorbing material is used to make it anechoic. The use of such a facility is required if swept frequency testing is to be performed to contain the test field and prevent interference to equipment not under test. Alternately, open field tests as outlined in SAE J1338 (see Ref. 3) could be used but are limited to discrete frequencies.

9.3 Apparatus:

(a) Anechoic chamber: The size, shape, and construction of an anechoic chamber can vary considerably depending upon the tests to be performed, the size of the EUT and the frequency range to be covered. Basically, an anechoic chamber consists of a shielded room with RF absorbing material mounted on its internal surfaces. The minimum size of the room is determined by the size of the test region needed, the size of the transmitting antennas, the clearances needed between the absorber and antennas, and the separation distance required between the transmitting antenna and the EUT. To create the test region (quiet zone), the absorber, antenna systems, and chamber shape are selected to reduce the amount of extraneous energy in the test region below a minimum value which will give the desired measurement accuracy. Since the performance of the absorber is a function of its construction (thickness, shape, material, etc.) and the angle of incident energy, the determination of the optimum location and construction of the absorber in an anechoic chamber to meet specified reflectivity requirements can be complicated. Guidelines for designing and using an anechoic chamber for EMC measurements are available (see Refs. 13-15). Table 2 gives a general recommended minimum thickness of the absorber for covering the enclosure walls which will provide at least 20 dB attenuation of the reflected power.

9.3 (Continued):

(b) Signal Source: Any commercially available signal source, power amplifier, and general purpose amplifier capable of supplying the necessary modulated and unmodulated power to develop the susceptibility test signals levels specified in the test plan may be used. Frequency accuracy shall be within ± 2%; Harmonics and spurious outputs shall not be more than -30 dB referred to the fundamental power.

(c) Radiating Antennas: Any standard antenna such as a log periodic (200 MHz - 1 GHz), and rectangular or ridged horns (1 - 8 GHz and 8 - 18 GHz bands) shall be used. Linear antennas yield more information about polarization if used.

(d) Sensing and Calibration Equipment: Any standard antenna with EMI meter or spectrum analyzer or calibrated field measuring probes can be used. Optimum results are obtained by using electrically small, isolated E-field probes, which remove many of the uncertainties associated with physically large receiving antennas. For a more detailed discussion and recommendations to avoid problems inherent in probing the fields around an EUT, see SAE Paper No. 830606 (see Ref. 16).

(e) Output Monitor: Appropriate instrumentation to monitor the performance of the EUT shall be used.

9.4 <u>Test Setup and Procedure</u>:

(a) The block diagram is shown in Fig. 17.

(b) Distance from the EUT to the transmitting antenna is a function of frequency, EUT, and antenna size. If the EUT or the largest transmitting antenna dimension is less than a wavelength (λ) the far-field begins at $\lambda/2\pi$. A uniform test field then is obtained at separation distances greater than λ. For electrically large EUT and/or for antennas with electrically large apertures, the separation distance should exceed d^2/λ where d is the largest dimension of the antenna or EUT.

(c) Fields should be generated, as required, with the specified antenna. Care should be taken so that the test equipment is not affected by the test signals. Test equipment, except for the antenna, should be outside the shielded enclosure.

(d) The specified field strength and polarization shall be established prior to the actual testing by substituting a field-measuring antenna in place of the EUT and by adjusting and recording the transmitter power required to obtain a specified field intensity from the transmitting antenna. (This calibration may be used for all subsequent testing provided that exactly the same EUT location is used.)

(e) The EUT shall be oriented in each orthogonal plane to determine maximum susceptibility.

9.4 (Continued):

(f) The entire frequency range from 0.2 - 18 GHz shall be scanned. Tests shall be conducted at not less than three frequencies per octave, representing the maximum susceptibilities within that octave. In addition, tests shall also be made at the EUT critical frequencies (local oscillator frequency, intermediate frequency and others) as specified in the test plan. Determine the threshold of susceptibility by increasing the test signal until degradation of performance is observed or the required test level is achieved.

9.5 Notes:

(a) Unless otherwise required in the equipment specification or approved plan, the test signals shall be modulated according to the following rules:

1. EUT's with video channels other than receivers, modulate 90 - 100% with a pulse of duration 2/BW and repetition rate equal to BW/1000, where BW is the video bandwidth.
2. Digital Equipment: Use pulse modulation with pulse duration(s) and repetition rate(s) equal to those used in the equipment.
3. Non-Tuned Equipment: Amplitude modulate 30% with the 1000 Hz tone or as otherwise required in the test plan.

(b) The EUT configuration shall simulate actual operating conditions as nearly as possible in terms of surrounding metal structure, lead length, and terminating impedances.

(c) RF power handling capability of absorber shall be adequate to insure safe operation.

(d) When required, a copper or brass ground plane (solid plate) shall be used that has a minimum thickness of 0.25 mm for copper or 0.63 mm for brass and is 2.25 m^2 or larger in area with the smaller side no less than 76 cm. The ground plane shall be bonded to the shielded room such that the DC bonding resistance shall not exceed 2.5 milliohms. In addition, the bonds shall be placed at distances no greater than 90 cm apart. For large equipment mounted on a metal test stand, the test stand shall be considered a part of the ground plane for testing purposes and shall be bonded accordingly. The faces of the test sample shall be located 10 + 2 cm from the edge of the ground plane. All leads and cables shall be within 10 ± 2 cm from the edge of the ground plane and shall be approximately 5 cm above the ground plane.

10. REFERENCES:

1. *SAE J1595, Electrostatic Discharge Test For Vehicles. To be published.

2. *SAE J1448 JAN84, Electromagnetic Susceptibility Measurements of Vehicle Components Using TEM Cells, 14 kHz - 200 MHz

3. *SAE J1338 JUN81, Open Field Whole-Vehicle Radiated Susceptibility, 10 kHz - 18 GHz, Electric Field

4. *SAE J1507 JAN87, Anechoic Test Facility Radiated Susceptibility, 20 MHz - 18 GHz, Electromagnetic Field.

5. Adams, J. W., Taggart, H. E., Kanda, M., and Shafer, J., "Electromagnetic Interference (EMI) Radiative Measurements for Automotive Applications," NBS Tech. Note 1014, June 1979

6. Natrella, M. G., "Experimental Statistics," NBS Handbook 91

7. Johnson, N. L. and Kotz, S., "Continuous Univariant Distributions," Vol. 2

8. Resnikoft, "Non-Central t Distribution"

9. Owen, D. B., "Handbook of Statistical Tables"

10. ISO/TR 7637/0, 1-1984 (E), "Road Vehicles - Electrical Interference by Conduction and Coupling: Part 0, General, and Part 1, Vehicles with Nominal 12 V Supply Voltage - Electrical Transient Conduction Along Supply Lines Only," July 1, 1984

11. Tippett, J. C., Chang, D. C., and Crawford, M. L., "An Analytical and Experimental Determination of the Cutoff Frequencies of Higher-Order TE Modes in a TEM Cell," NBSIR 76-841, June 1976

12. Tippett, J. C., Modal Characteristics of Rectangular Coaxial Transmission Line, Thesis submitted June 1978 for degree of Doctor of Philosophy to University of Colorado, Electrical Engineering Dept., Boulder, CO

13. Nichols, F. J., and Hemming, L. H., "Recommendations and Design Guides for the Selection and Use of RF Shielded Anechoic Chamber in the 30-1000 MHz Frequency Range," IEEE Inter. Symp. on EMC., Boulder, CO, August 18-20, 1981, pp 457-464

14. *Kinderman, J. C., et al., "Implementation of EMC Testing of Automotive Vehicles," SAE Paper 810333, February 1981

15. *Vrooman, "An Indoor 60 Hz to 40 GHz Facility for Total Vehicle EMC Testing," SAE Paper 821011, June 1983

16. *Bronaugh, E. L., and McGinnis, W. H., "Whole-Vehicle Electromagnetic Susceptibility Test in Open-Area Test Sites: Applying SAE J1338," SAE Paper 830606

*Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096.

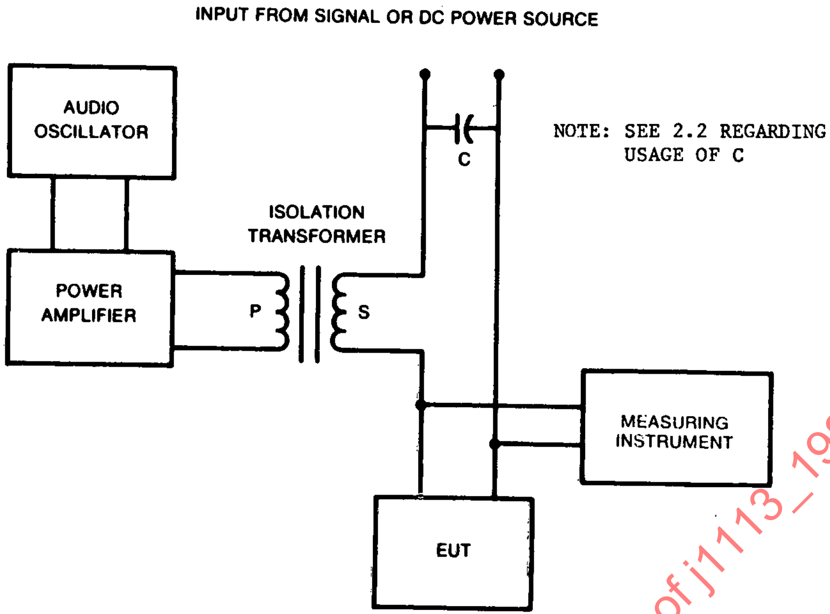


FIGURE 1 - Test setup for measuring conducted susceptibility, 30 Hz to 250 kHz, all leads.

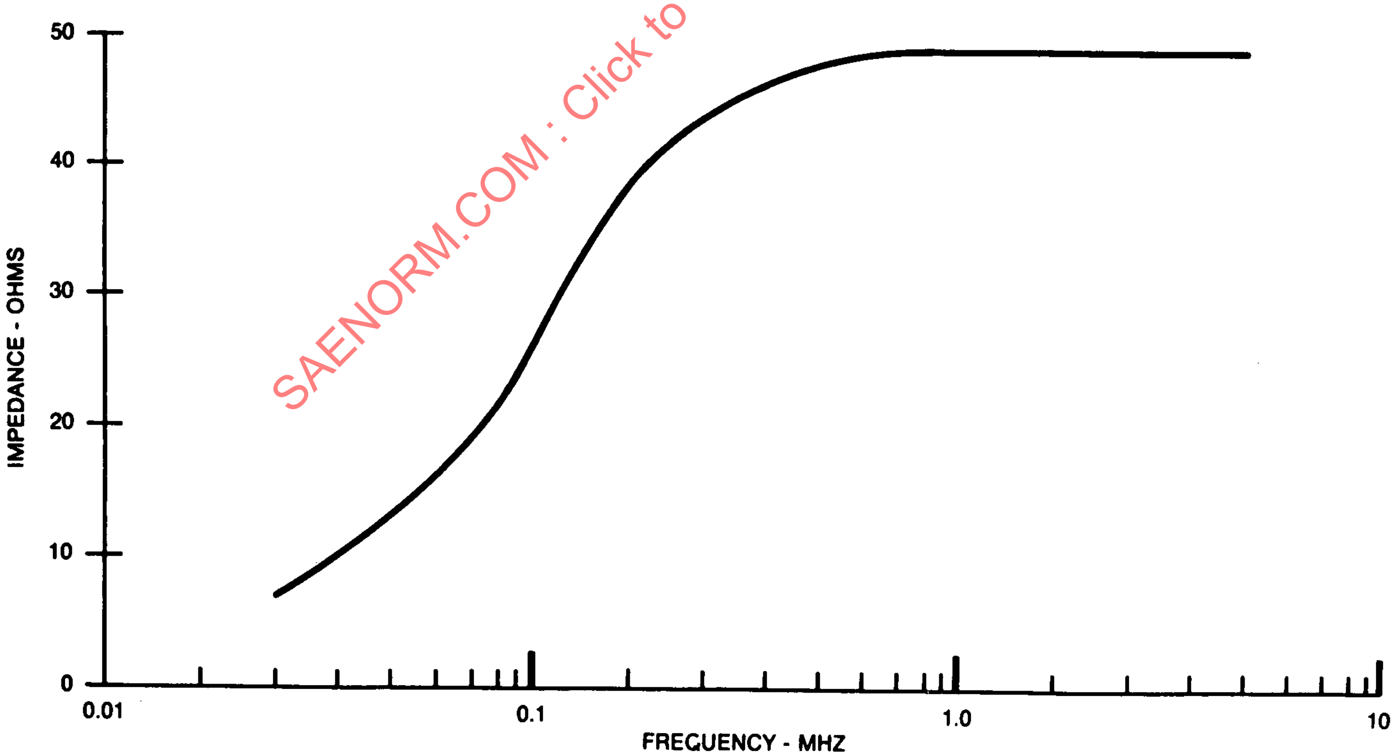


FIGURE 2 - Line impedance stabilization network reference impedance, 50 kHz to 5 MHz, (50 μh).

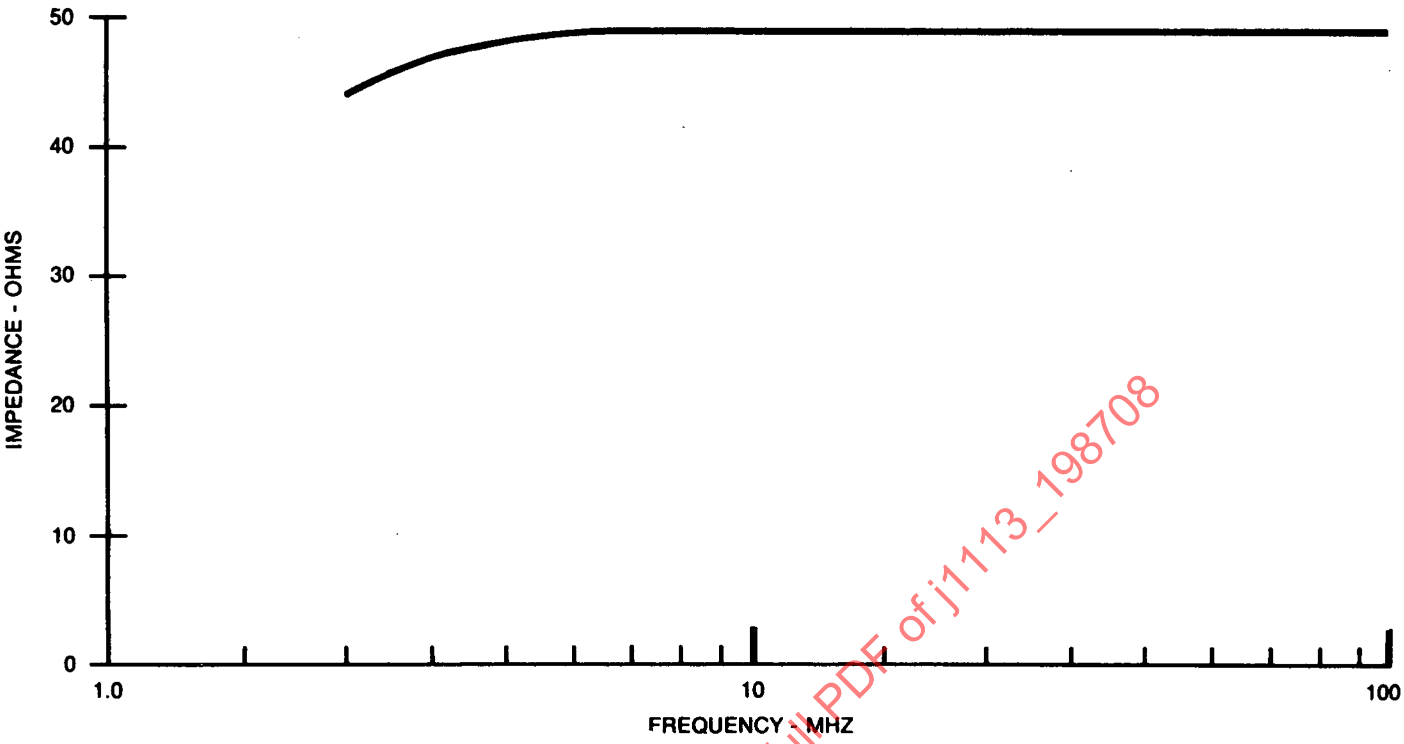


FIGURE 3 - Line impedance stabilization network reference impedance, 5 MHz to 100 MHz, (5 μh).

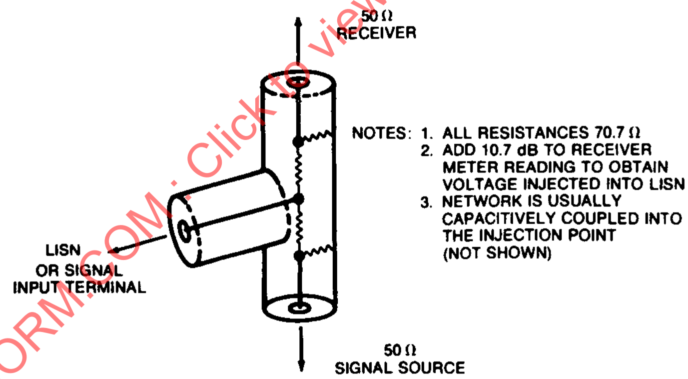


FIG. 4(A) - $Z_G = Z_R = 50\ \Omega$

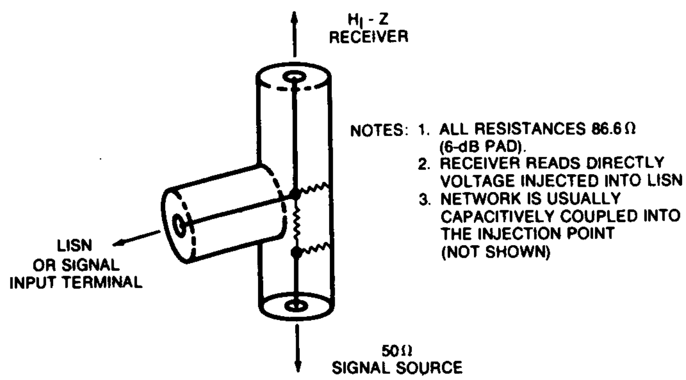


FIG. 4(B) - $Z_G = 50\ \Omega$, $Z_R >> 50\ \Omega$

FIGURE 4 - Test source injection network

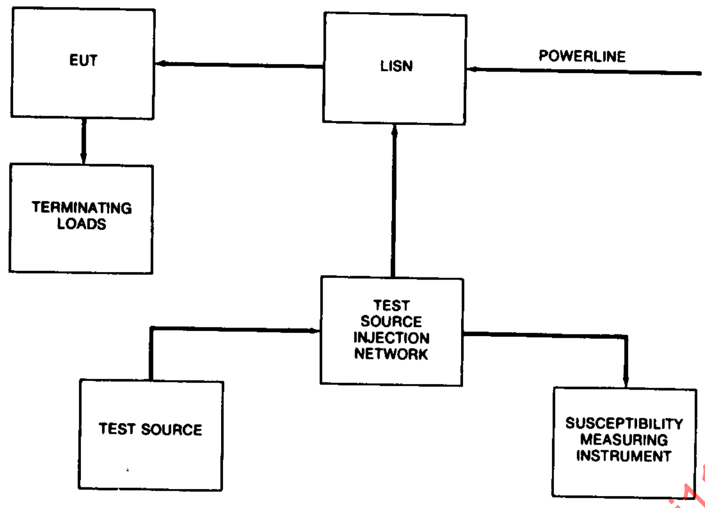


FIGURE 5 - Equipment block diagram for measuring conducted susceptibility, 50 kHz to 100 MHz, powerline only.

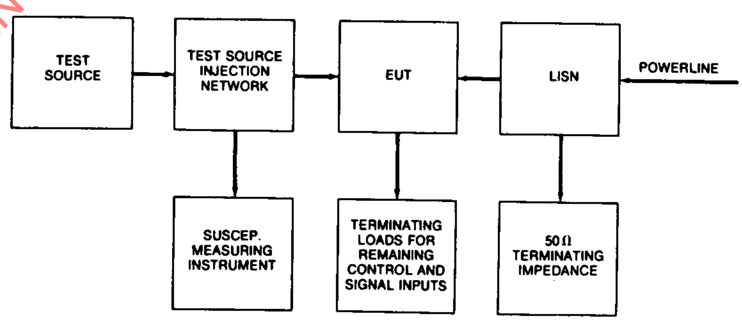


FIGURE 6 - Equipment block diagram for measuring conducted susceptibility, 50 kHz to 100 MHz, control and signal inputs.

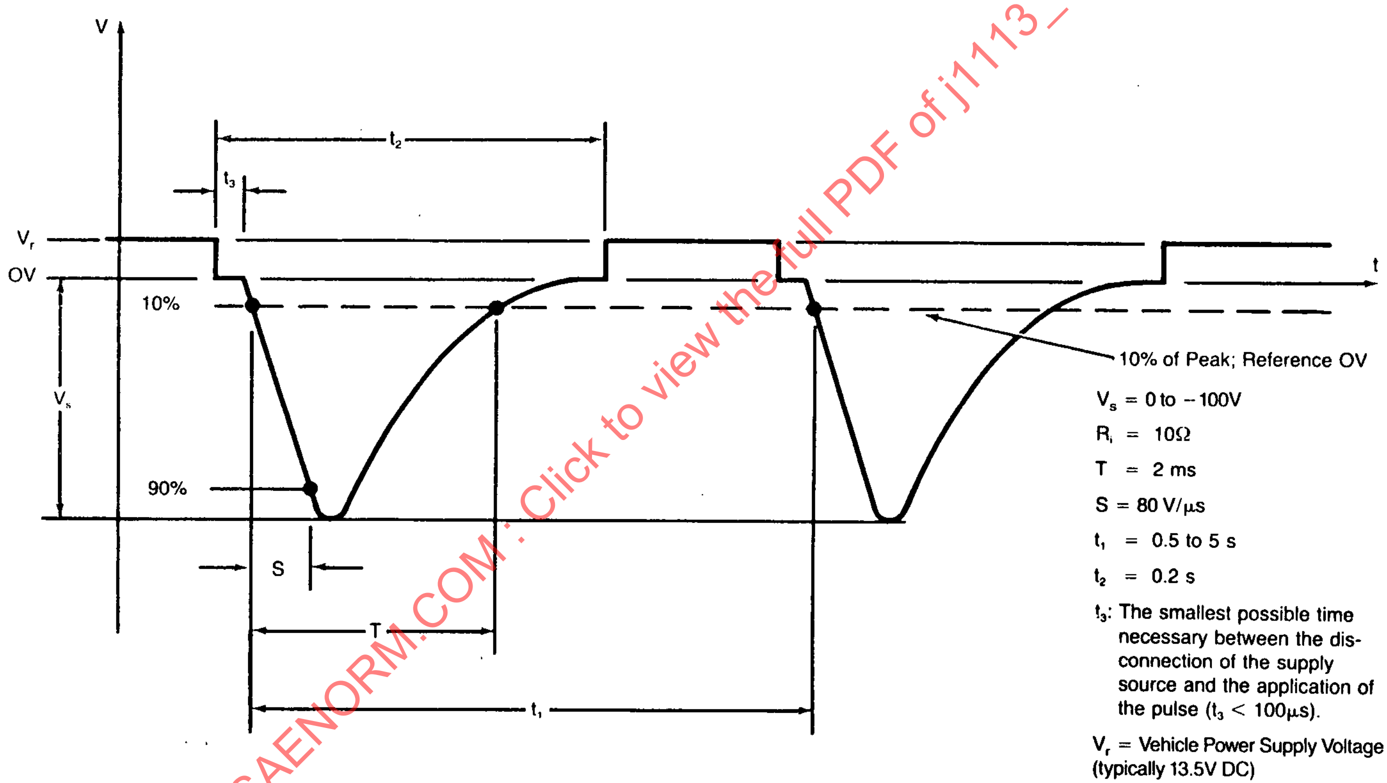


FIGURE 7A - Test pulse 1 (disconnection from inductive loads with device under test remaining connected directly in parallel with this inductive load).

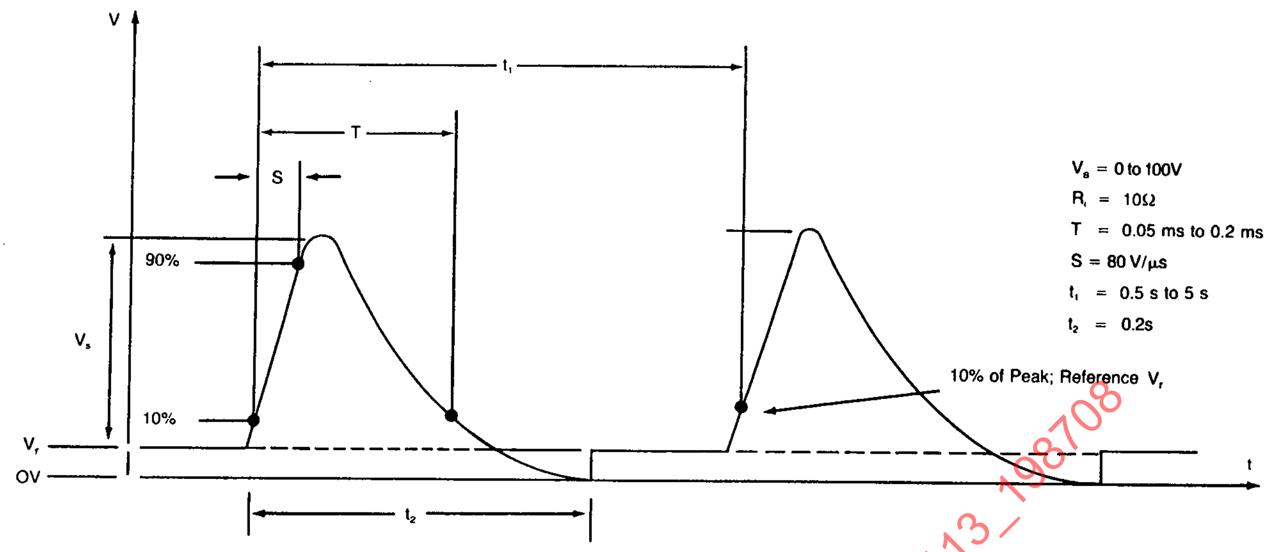


FIGURE 7B - Test pulse 2 (sudden interruption of a series current).

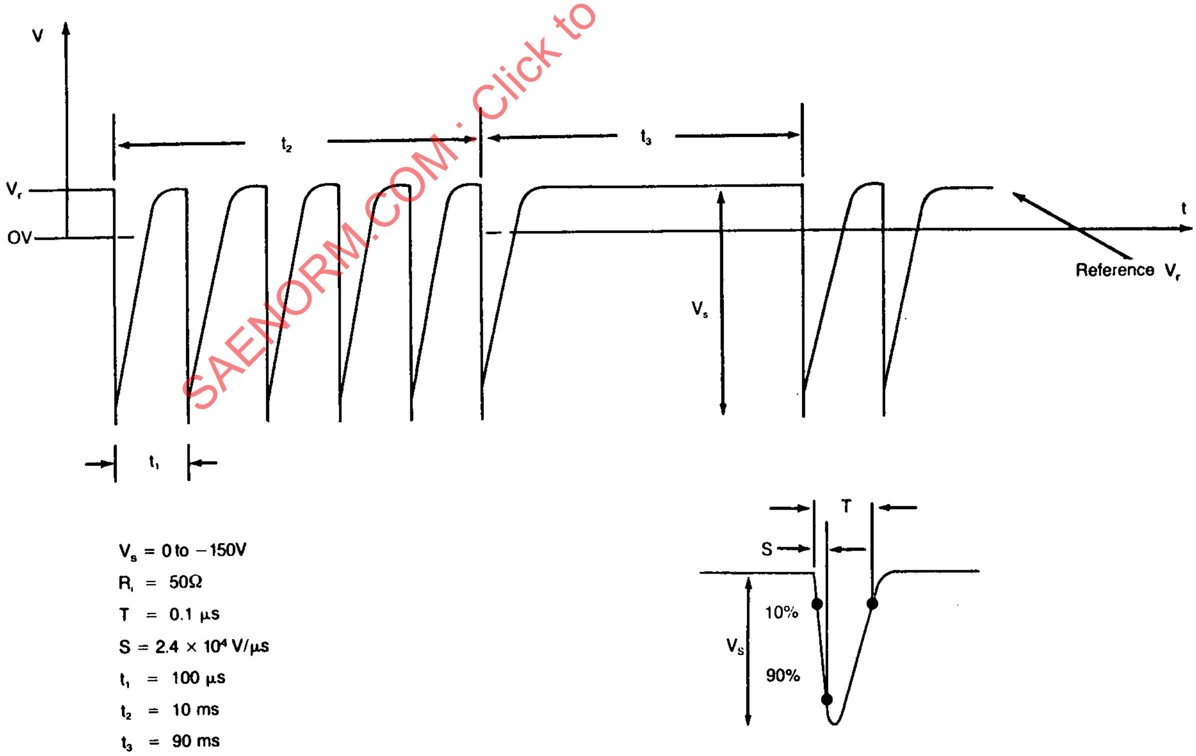


FIGURE 7C - Test pulse 3A (switching spikes).

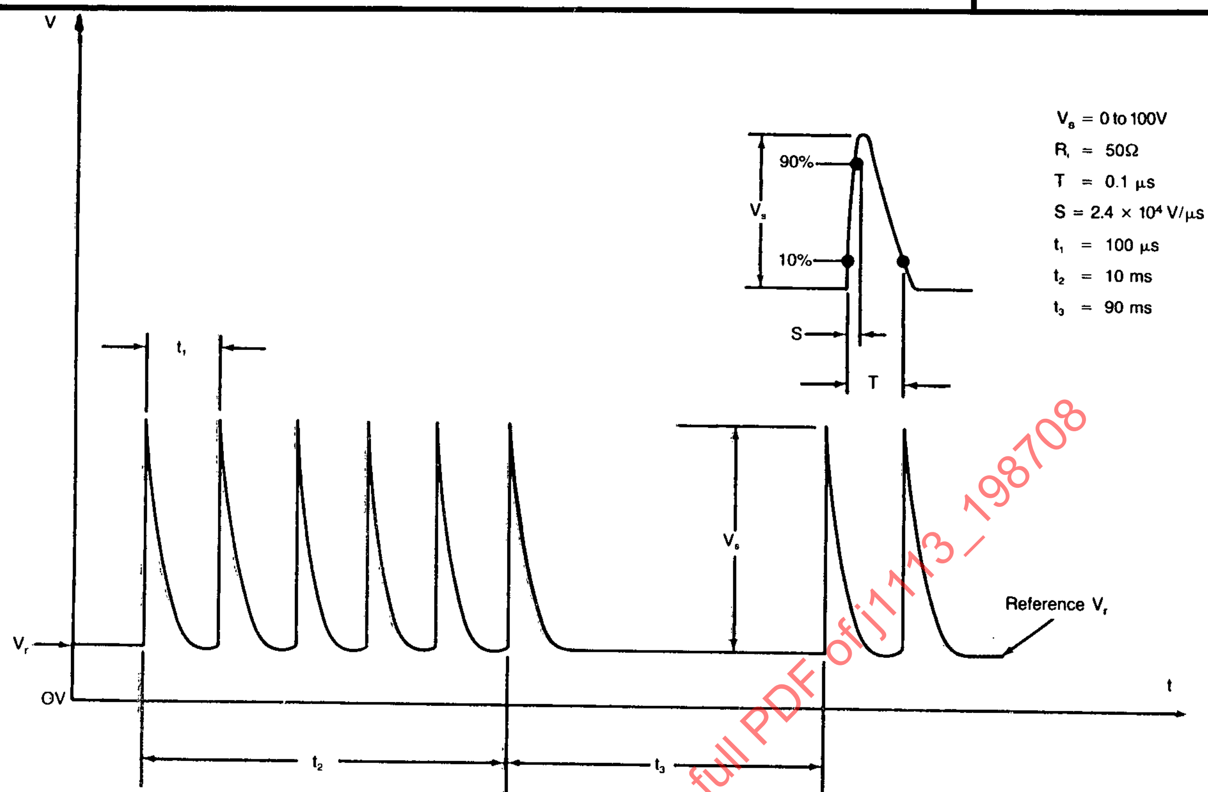


FIGURE 7D - Test pulse 3B (switching spikes).

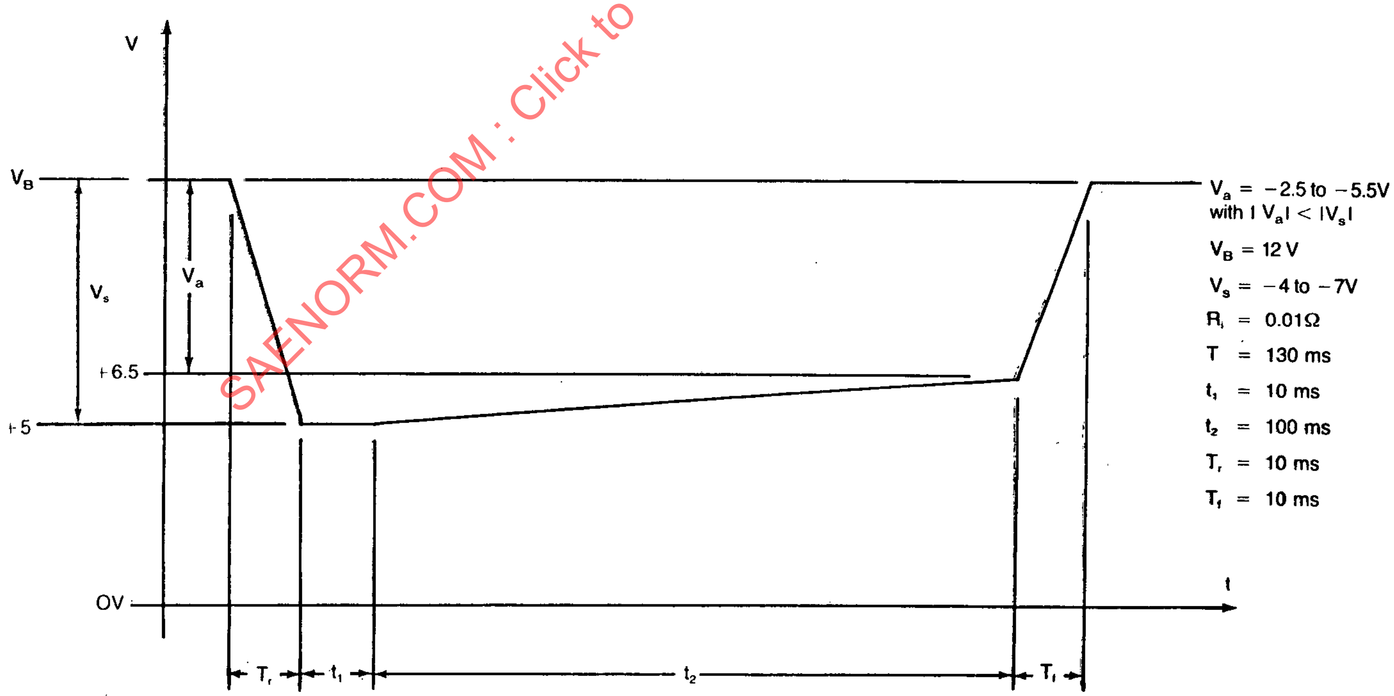
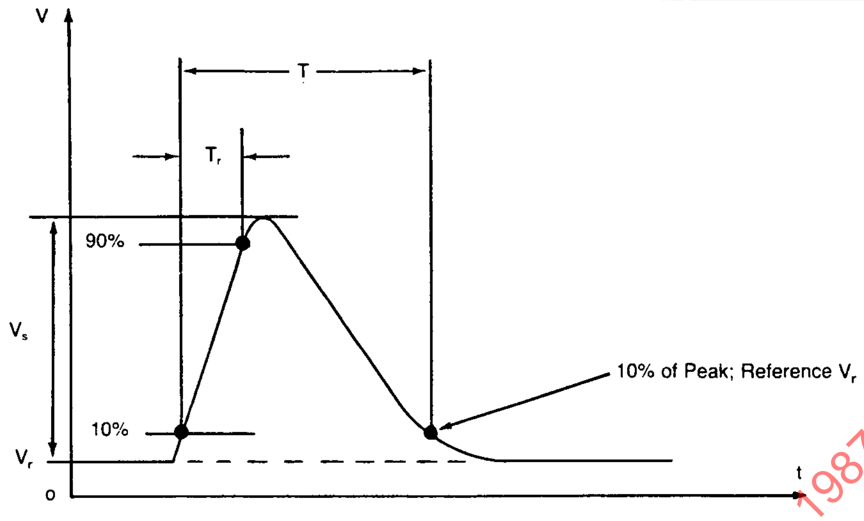


FIGURE 7E - Test pulse 4 (single pulse, for example, starter motor engagement disturbance).



V_s = 25 to 120V
T = 40 to 400 ms
T_r = 5 to 10 ms
R_i = 0.5 to 4Ω

Notes: General considerations of the dynamic behavior of alternators during load dump:

1) The internal resistance of an alternator in the case of load dump is mainly a function of speed and excitation current.
The internal resistance of the load dump simulator shall be obtained from the following relationship:

$$R_i = \frac{10\ V_{nom}\ N_{actual}}{0.8\ I_{rated}\ 12000\ min^{-1}}$$

where V_{nom} = specified voltage of the generator, I_{rated} = specified current at a speed of 6000 min^{-1} (see ISO 8854), and N_{actual} = actual alternator speed (min^{-1}).

R_i shall represent a value corresponding to specified values of excitation current and speed.

2) The parameters are interrelated such that high values of V_s, R_i and T correspond to each other and low values vice versa

3) Depending on the characteristics of the EUT (possibly including Zener diodes and varistors) the observed voltage waveform across the EUT may be quite different from the open circuit waveform.

FIGURE 7F - Test pulse 5 (Load dump, single pulse).

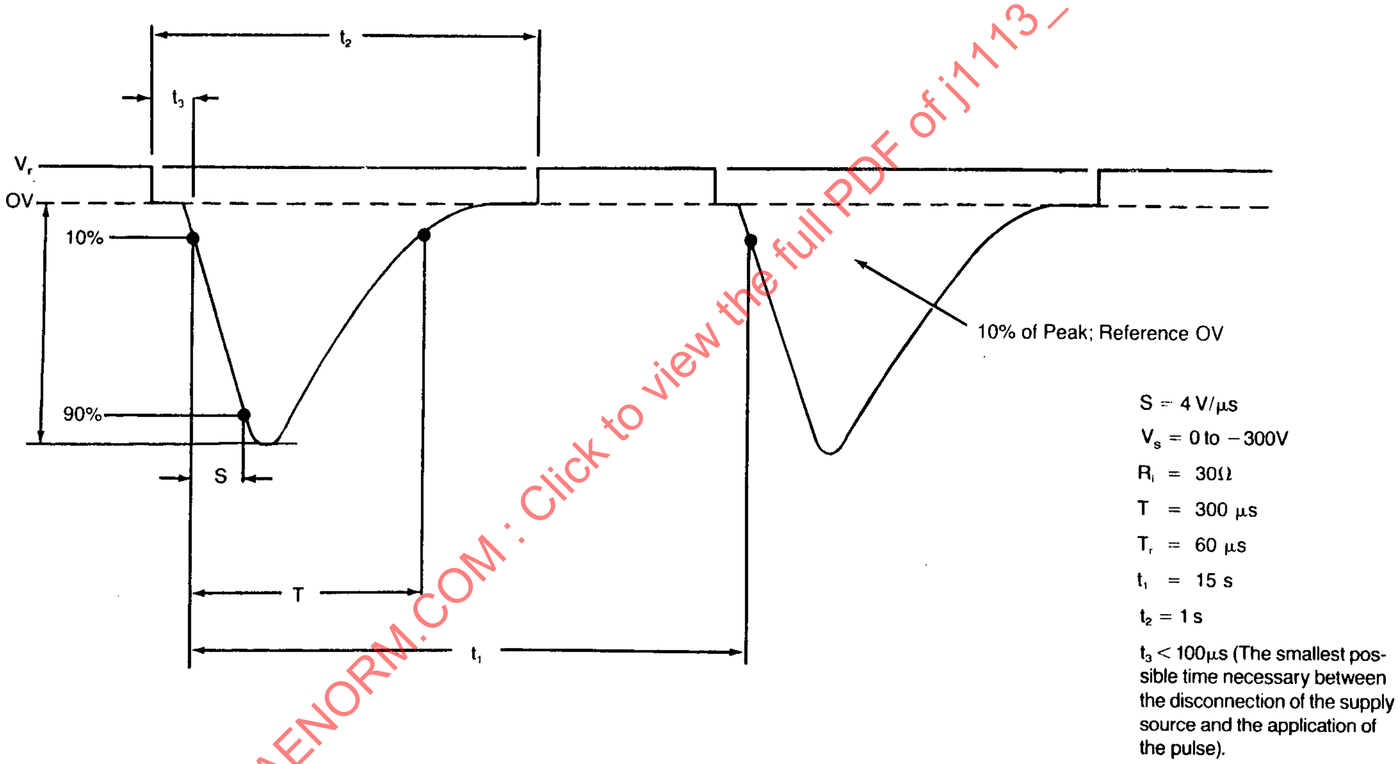


FIGURE 7G - Test pulse 6 (ignition coil current interruption).

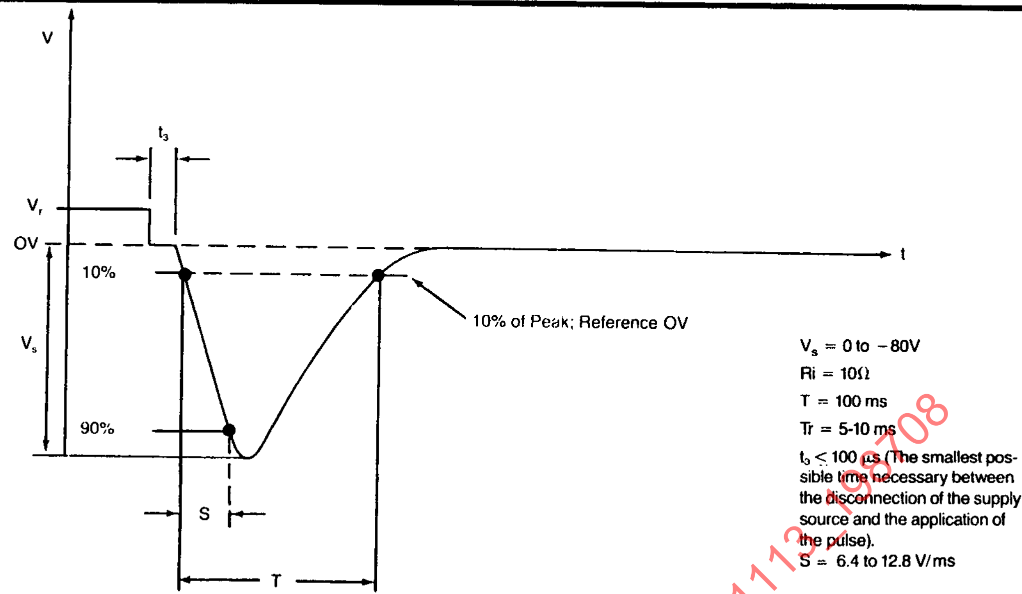


FIGURE 7H - Test pulse 7 (single pulse, for example, alternator field transient at engine turn-off).

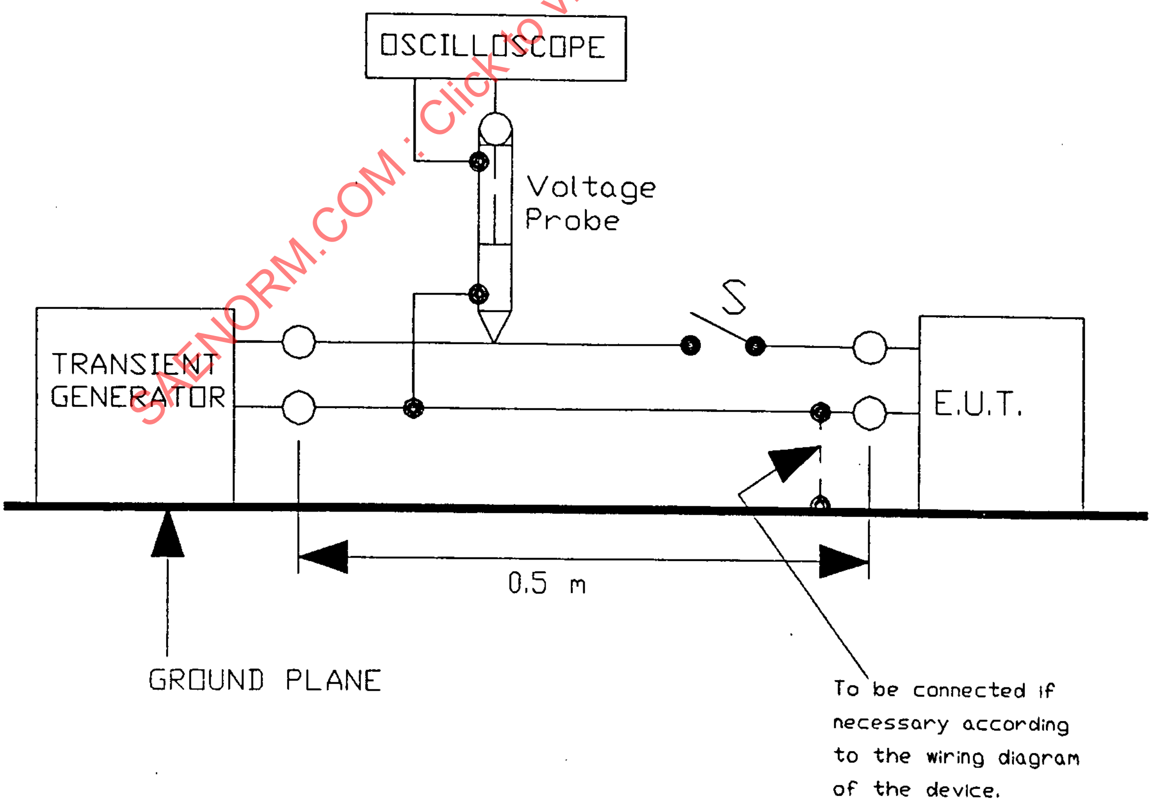


FIGURE 8 - Test setup for conducted transient susceptibility.

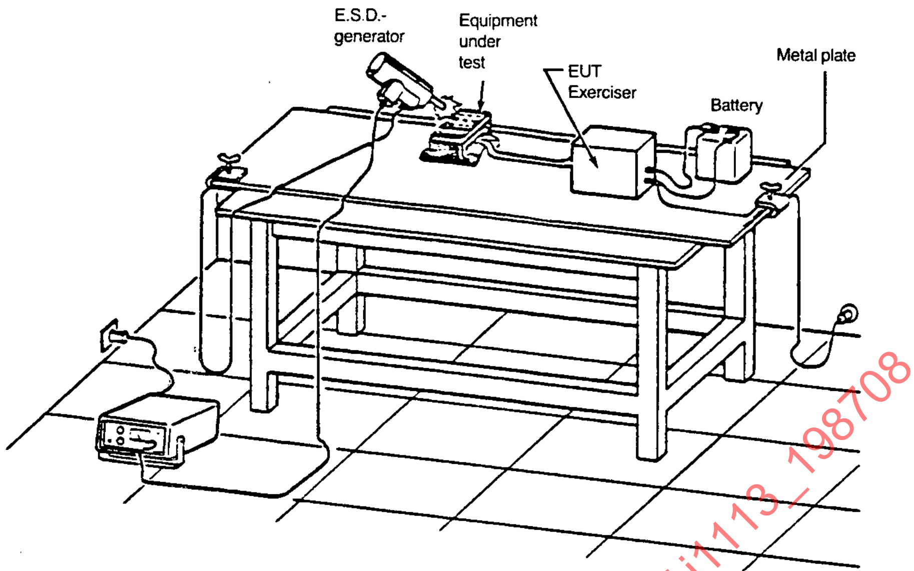


FIGURE 9A - Laboratory testing of devices intended for installation on ground-connected chassis parts of vehicle.

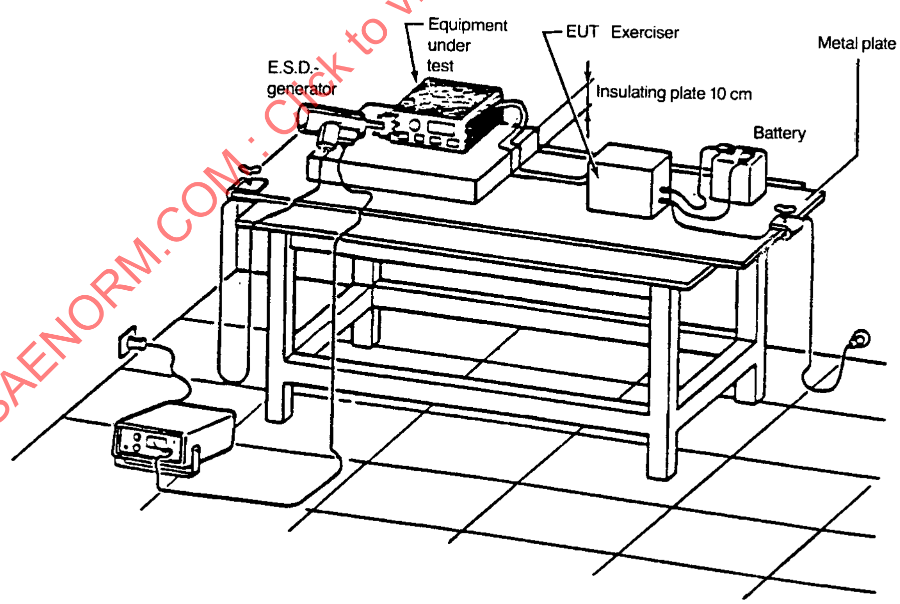


FIGURE 9B - Laboratory testing of devices intended for installation on insulating plastic parts on vehicle.

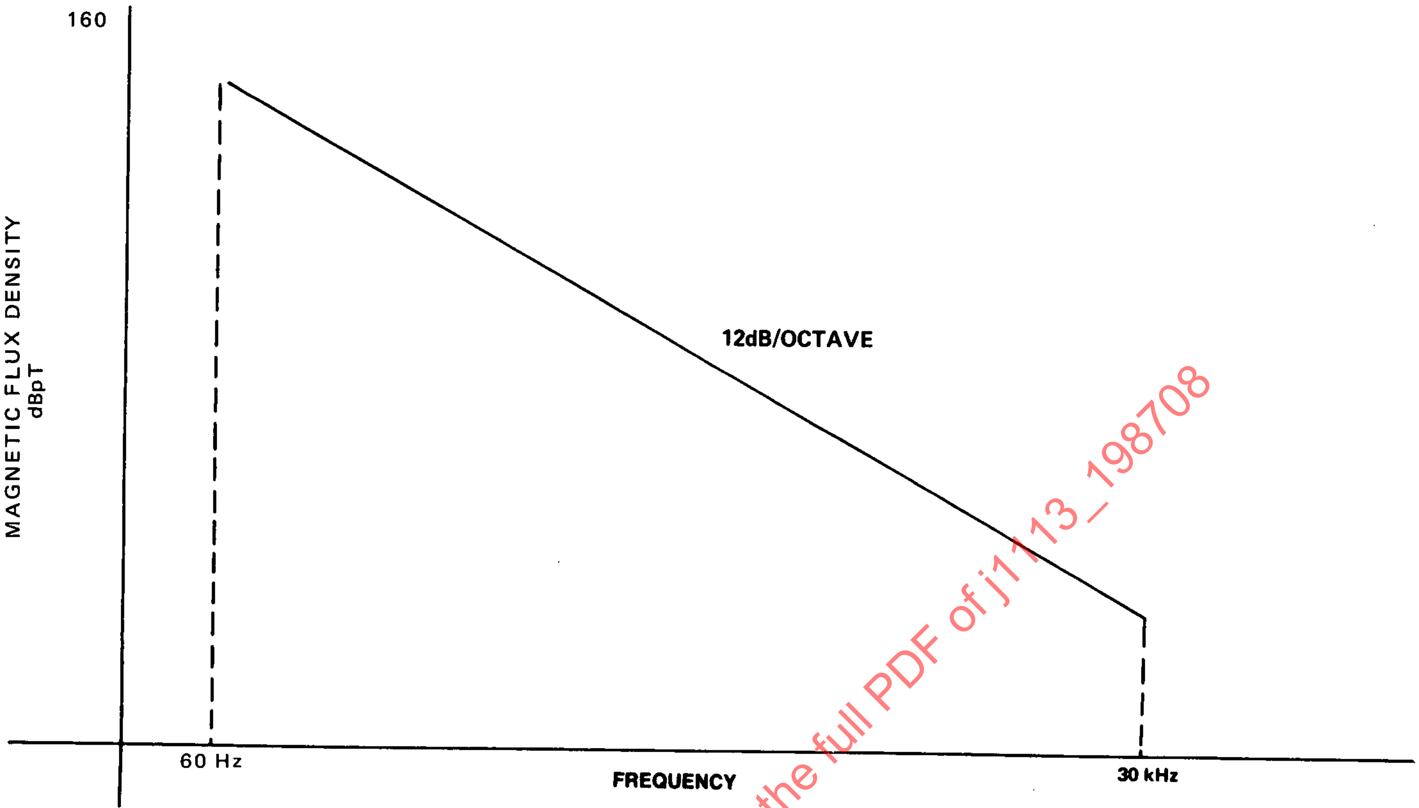


FIGURE 10 - Magnetic flux density versus frequency.

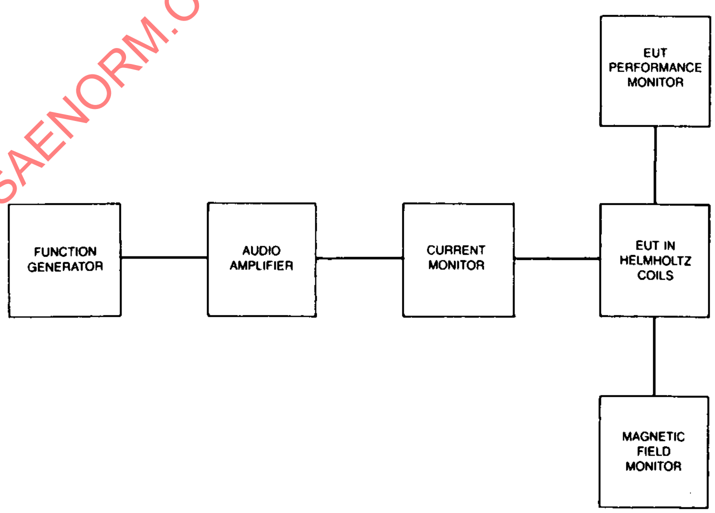


FIGURE 11 - Block diagram for magnetic field susceptibility testing.

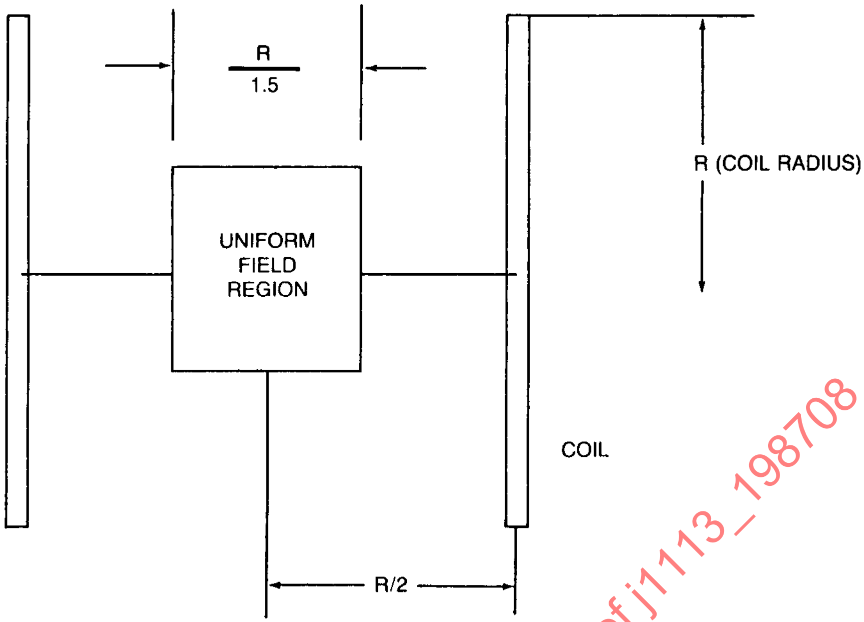


FIGURE 12 - Helmholtz coil configuration.

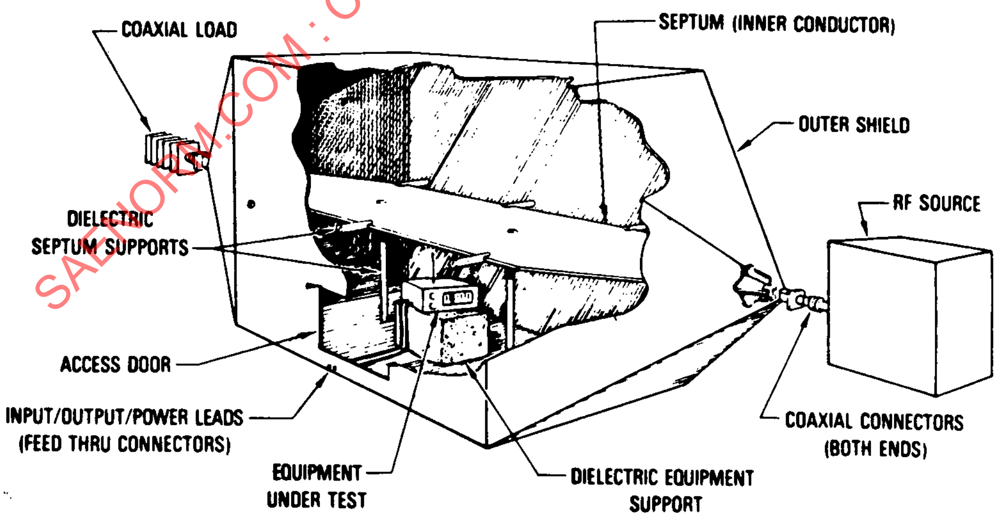
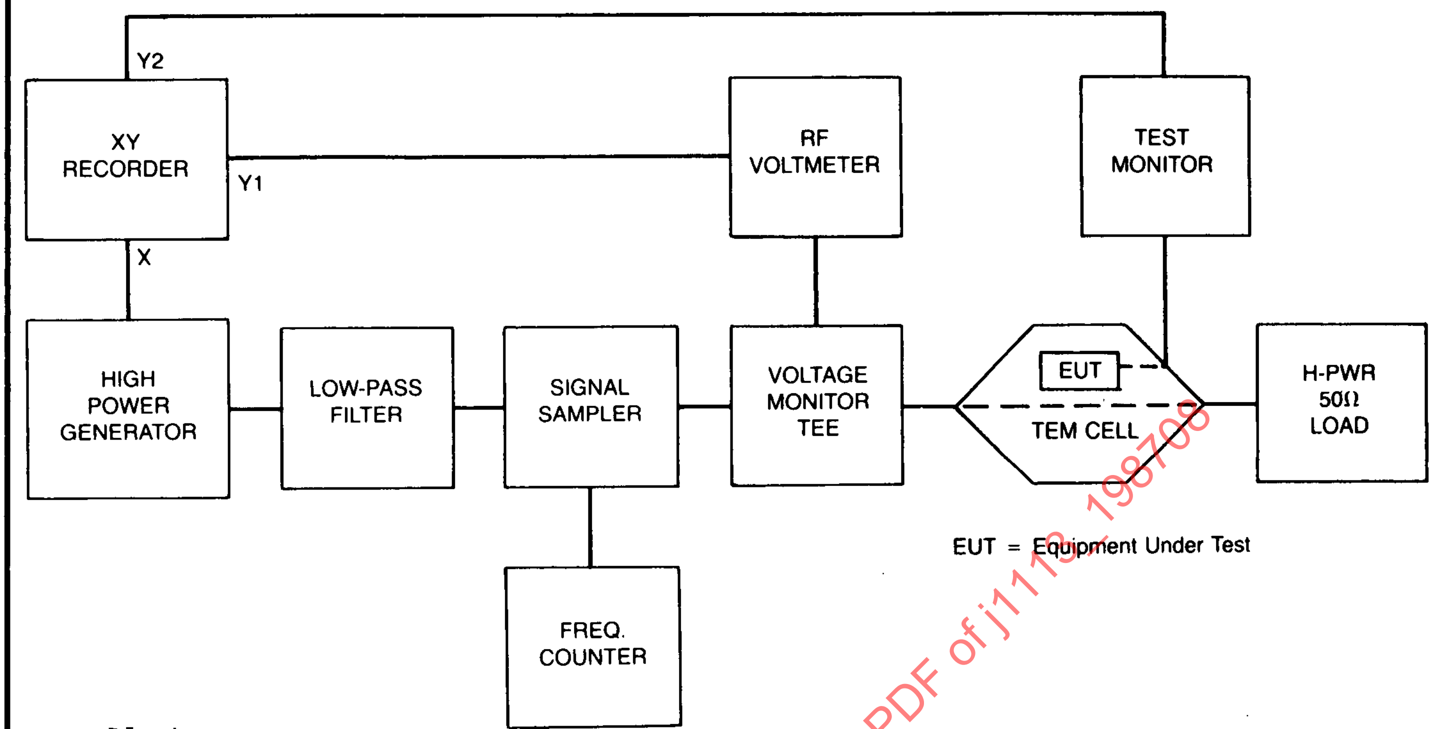
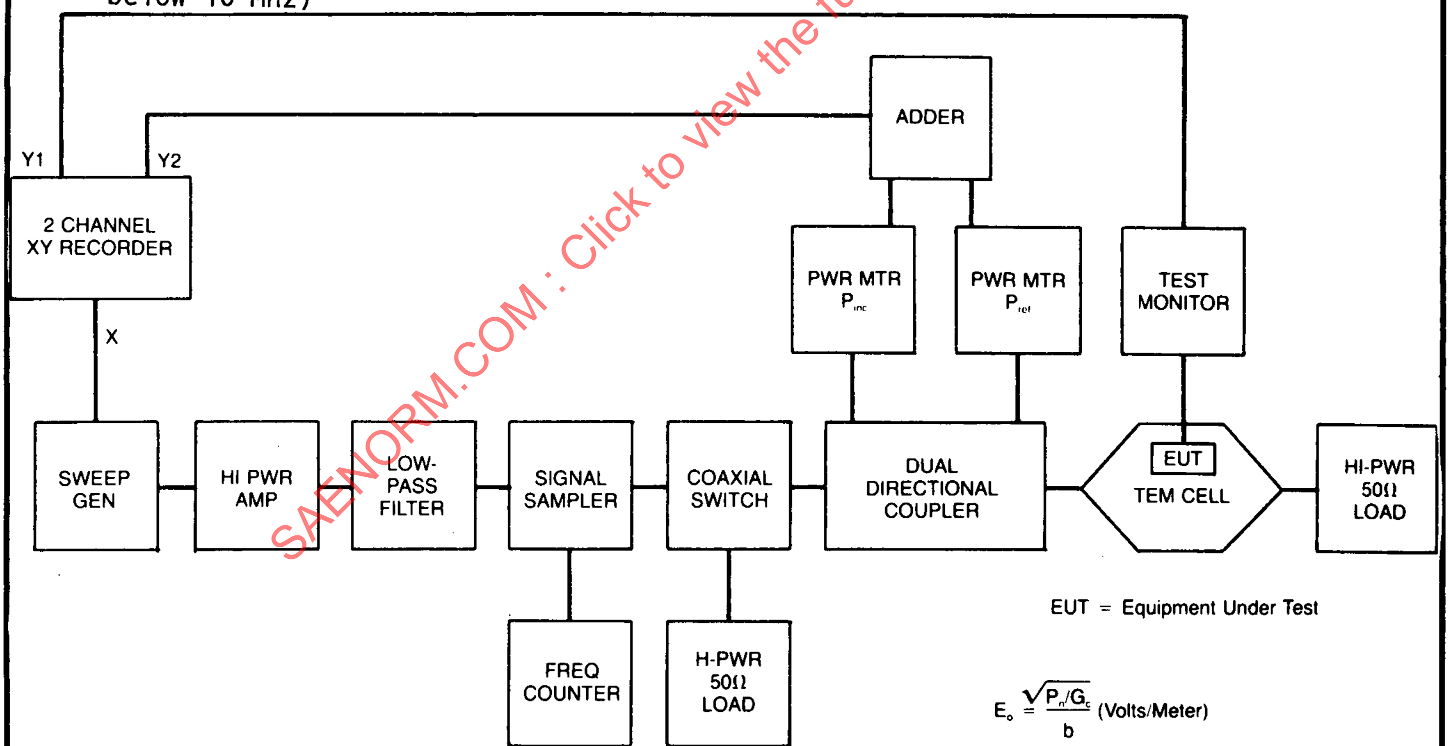


FIGURE 13 - Cut-away view of TEM cell used for radiated susceptibility testing. Figure shows placement of EUT and associated input, output and monitoring leads inside the cell.



Block diagram of system for susceptibility testing of equipment (used typically below 10 MHz)



Block diagram of system for susceptibility testing of equipment (10 - 500 MHz)

FIGURE 14 - Block diagrams of TEM cell systems for susceptibility testing of equipment.

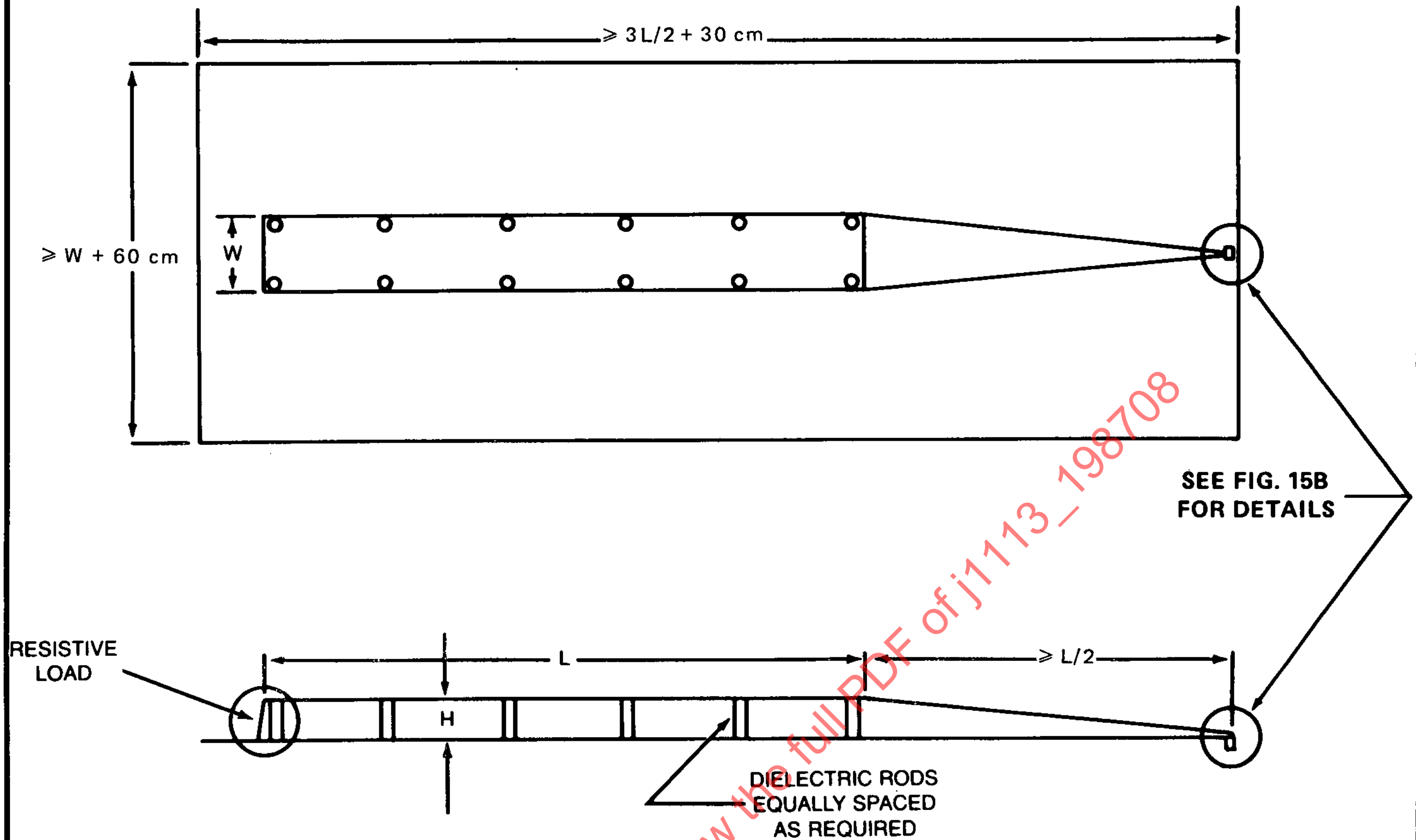


FIGURE 15A - Design for a strip line.

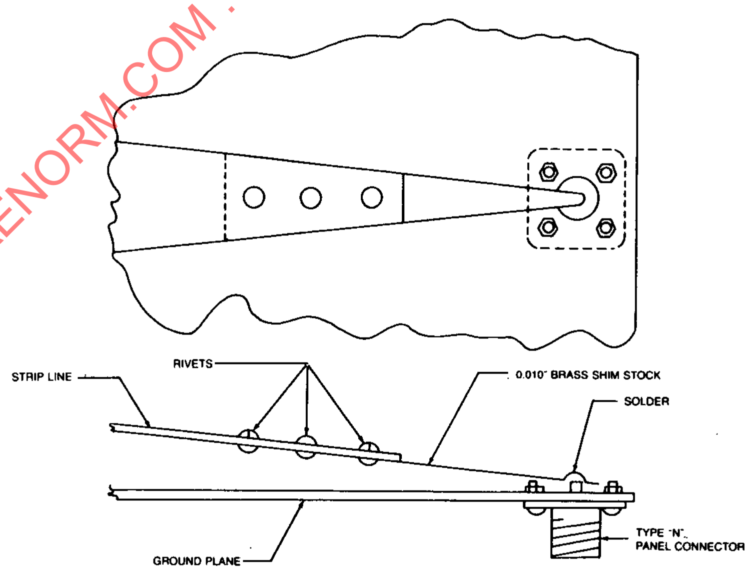


FIGURE 15B - Details for strip line design.

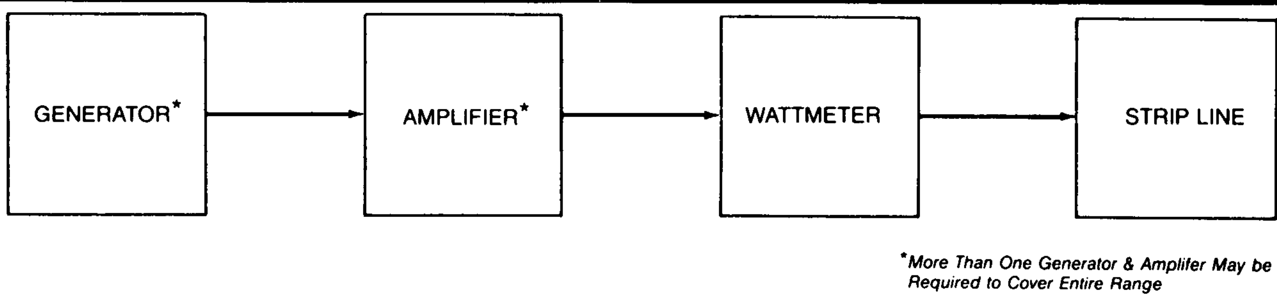


FIGURE 16 - Block diagram for strip line.

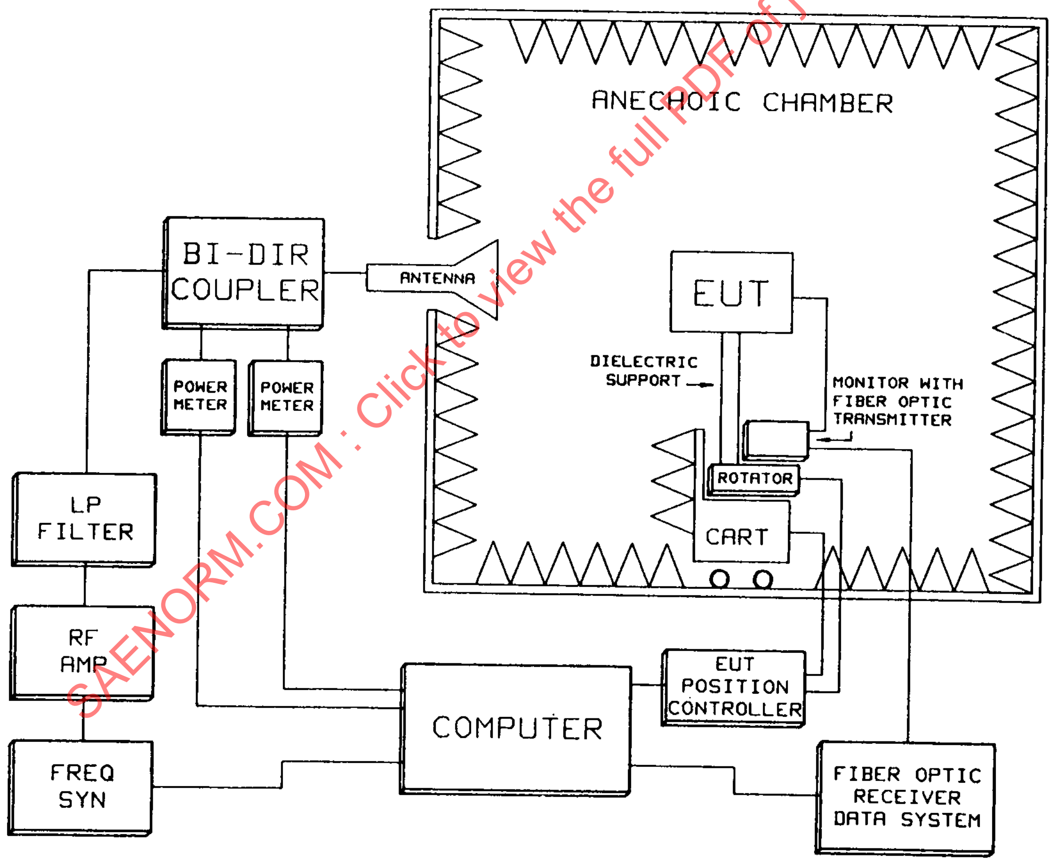


FIGURE 17 - Block diagram of system for susceptibility testing of equipment (0.2 to 18 GHz).

TABLE 1 - TEM Cell Dimensions

Cell #	Recommended upper frequency (MHz)	Cell form factor a/b	Plate separation b (cm)	Center septum W (cm)	TE_{01} Cutoff/multimode frequency Propagation (MHz)	Resonance *(MHz)
1	40	1.0	150	124.5	29	44
2	60	1.0	100	83	43	66
3	80	1.5	60	68	66	86
4	100	1.0	60	50	72	110
5	120	1.5	40	45.6	100	129
6	150	1.67	30	36	128	162
7	160	1.5	30	34.2	134	172
8	200	1.0	30	24.9	143	220

*Resonance frequency calculation based upon resonance length of cell equal to 3a. (for example, 1.5 X width)

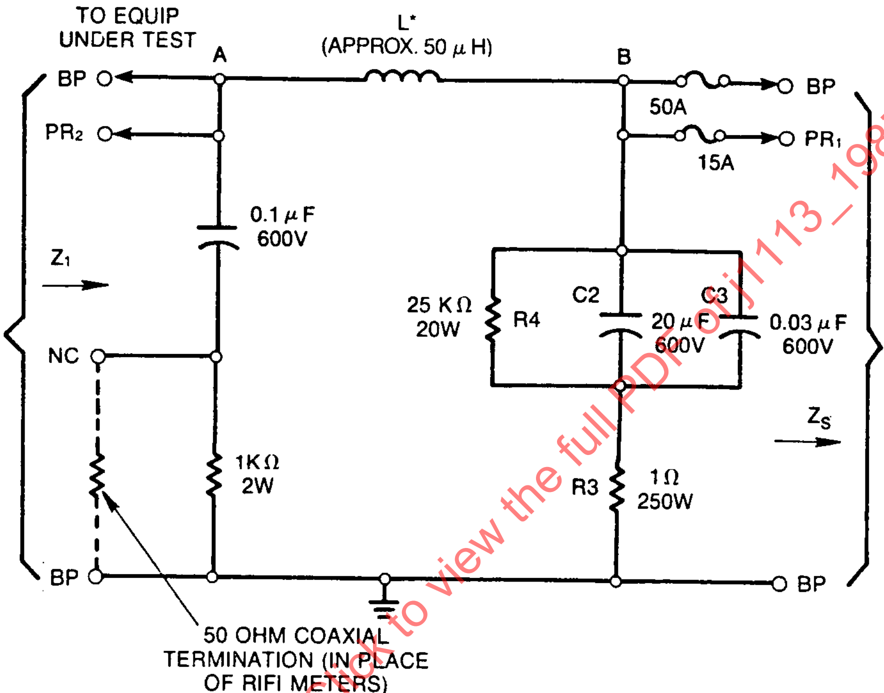
TABLE 2 - Recommended minimum thickness of absorber for covering enclosure walls

Frequency MHz	Absorber Thickness in (cm)
200	36 (91)
300	24 (61)
500-1000	18 (46)

APPENDIX A

Line Impedance Stabilization Networks

The following schematic diagrams are suggested for use in constructing the line impedance stabilization networks required for performing the conducted susceptibility measurements outline in Section 3. Care must be taken in their use to insure that the impedances specified in Figs. 3 and 4 are obtained.



Z_1 - Impedance presented to the equipment when connected for measurements.

Z_S - Impedance of the power source used.

BP - Heavy duty binding posts (mfr. standard electric time co.)

PR_1 - Power receptacle, 115 V, 15 A (3-wire polarized twist lock, male base).

PR_2 - Power receptacle, 115 V, 15 A (3-wire non-polarized, "U" shaped grounding slot).

NC - Type "N" connector (UG-58/U) panel mounting.

L° - Coil - 26 turns of no. AWG-6 stranded wire with 600 V insulation wound on 5.5 in (14 cm) diameter coil form.

CASE - 17-1/2"L x 17-1/2"W x 8-3/4"H (44.4 cm L x 44.4 cm W x 22.2 cm H) brass (divided in two sections by a brass plate 17-1/2" x 8-5/8" x 1/16" (44.4 cm x 21.9 cm x 1.6 mm) thick).

NOTE: Dual line stabilization network consists of two of the above networks.

FIGURE A1 Line inpedance stabilization network (LISN), 50 kHz - 5 MHz.